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(54) **Scan module for optical scanner**

(57) An integrated optical module for an optical scanner has a lens (24) spaced from a vertical-cavity surface-emitting laser (VCSEL) (28) by a spacer (62). The module, in an alternative embodiment, may include a wafer frame (12), a suspended mirror (14) mounted for oscillation on the frame, a wafer substrate (108) bonded beneath the frame and a wafer cover (109) bonded above the frame. The cover includes a mirror travel stop (116) to protect the mirror against shock. A VCSEL mounted to the wafer cover produces a beam which is shaped and deflected by a diffractive optical element (22,24) onto the oscillating mirror. The reflected beam passes out of the module toward an indicia to be read. Large numbers of such devices may be fabricated relatively cheaply using wafer-scale processing and assembly technology. Three large wafers (1100,1102,1104) are fabricated corresponding respectively to arrays of substrates, frames and covers. The large wafers are bonded together in a sandwich arrangement, and are then diced to produce the individual scan modules. The modules may provide either one-dimensional or two-dimensional scanning.

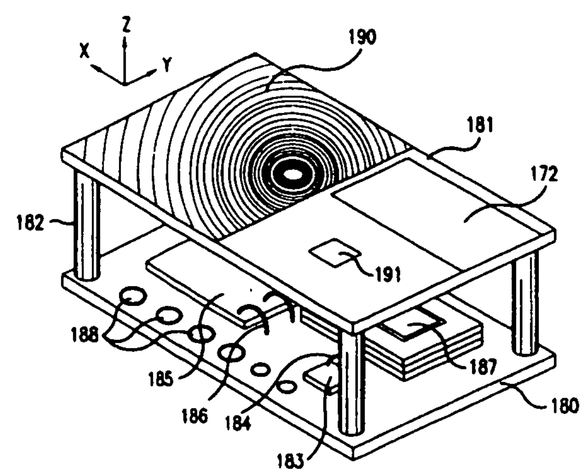

FIG.4B

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Description

The invention relates to optical scanners and in particular to a novel miniature scan engine/module for such scanners, preferably but not necessarily using wafer technology and incorporating a vertical cavity surface emitting laser diode (VCSEL). The invention further extends, more generally to an integrated optical module using VCSEL technology.

Various optical readers and optical scanning systems have been developed heretofore for reading indicia such as bar code symbols appearing on a label or on the surface of an article. The bar code symbol itself is a coded pattern of indicia comprised of a series of bars of various widths spaced apart from one another to bound spaces of various widths, the bars and spaces having different light reflecting characteristics. The readers in scanning systems electro-optically transform the graphic indicia into electrical signals, which are decoded into alphanumeric characters that are intended to be descriptive of the article or some characteristic thereof. Such characteristics are typically represented in digital form and utilized as an input to a data processing system for applications in point-of-sale processing, inventory control and the like. Scanning systems of this general type have been disclosed, for example, in U.S. Patents US-A-4,251,798; US-A 4,369,361; US-A-4,387,297; US-A-4,409,470; US-A-4,760,428; and US-A-4,896,026. As disclosed in some of the above patents, one embodiment of such a scanning system resides, inter alia, in a hand held, portable laser scanning device supported by a user, which is configured to allow the user to aim the scanning head of the device, and more particularly, a light beam, at a targeted symbol to be read.

The light source in a laser scanner bar code reader is typically a gas laser or semiconductor laser. The use of semiconductor devices as the light source is especially desirable because of their small size, low cost and low voltage requirements. The laser beam is optically modified, typically by an optical assembly, to form a beam spot of a certain size at the target distance. It is preferred that the cross section of the beam spot at the target distance be approximately the same as the minimum width between regions of different light reflectivity, i.e., the bars and spaces of the symbol. At least one bar code reader has been proposed with two light sources to produce two light beams of different frequency.

One laser-based bar code scanner relevant to the present invention is disclosed in U.S. Patent US-A-5,144,120 to Krichever et al. which employs laser, optical and sensor components in conjunction with a so-called "mirrorless" scanner arrangement. One or more of these components are mounted on a drive for repetitive reciprocating motion either about an axis or in a plane to effect scanning.

Another proposed bar code scanner employs electronic means for causing the light beam to scan a bar code symbol, rather than using a mechanical device. A linear array of light sources activated one at a time in a regular sequence may be imaged upon the bar code symbol to simulate a scanned beam. Instead of a single linear array of light sources, a multiple-line array may be employed, producing multiple scan lines. Such a scanner is disclosed in U.S. Patent US-A-5,258,605.

Typically, the semiconductor lasers used in such bar code scanners is an edge-emitting injection laser in which the laser beam is emitted from the p-n junction region on a polished end face of the device.

By their physical nature, these known edge-emitting injection lasers emit a beam from a thin region at the p-n junction. A laser beam emanating from a thin source has a large beam divergence which makes focusing difficult and results in a wide range of variability in performance from laser to laser.

A more recently developed form of semiconductor laser is the vertical-cavity surface-emitting laser diode (VCSEL), such as described in "Efficient Room-Temperature Continuous-Wave AlGaInP/AlGaAs Visible (670 nm) Vertical-Cavity Surface Emitting Laser Diodes" by R P Schneider et al. published in IEEE Photonics Technology Letters, Vol. 6, No. 3, March 1994. Reference is also made to U.S. patents US-A-5,283,447; US-A-5,285,455; US-A-5,266,794; US-A-5,319,496; and US-A-5,326,386, for background information.

The VCSEL has a substantial surface area from which the laser beam is emitted; this area may be patterned. Thus, the beam produced is less divergent in one dimension than with known edge-emitting type semiconductor laser diodes. The output beam is round, and is virtually not astigmatic. Furthermore, VCSELs typically operate at significantly lower currents than edge-emitting laser diodes. Therefore, it also generates less heat.

In the laser beam scanning systems known in the art, a single laser light beam is directed by a lens or other optical components along the light path toward a target that includes a bar code symbol on the surface. The moving-beam scanner operates by repetitively scanning the light beam in a line or series of lines across the symbol by means of motion or a scanning component, such as the light source itself or a mirror disposed in the path of the light beam. The scanning component may either sweep the beam spot across the symbol and trace a scan line across the pattern of the symbol, or scan the field of view of the scanner, or do both.

Bar code reading systems also include a sensor or photodetector which detects light reflected or scattered from the symbol. The photodetector or sensor is positioned in the scanner in an optical path so that it has a field of view which ensures the capture of a portion of the light which is reflected or scattered off the symbol, detected, and converted into an electrical signal. Electronic circuitry and software decode the electrical signal into a digital representation of the data represented by the symbol that has been scanned. For example, the

analog electrical signal generated by the photodetector is converted by a digitizer into a pulse or modulated digitized signal, with the widths corresponding to the physical widths of the bars and spaces. Such a digitized signal is then decoded, based on the specific symbology used by the symbol, into a binary representation of the data encoded in the symbol, and subsequently to the alpha numeric characters so represented.

The decoding process of known bar code reading system usually works in the following way. The decoder receives the pulse width modulated digitized signal from the digitizer, and an algorithm, implemented in the software, attempts to decode the scan. If the start and stop characters and the characters between them in the scan were decoded successfully and completely, the decoding process terminates and an indicator of a successful read (such as a green light and/or an audible beep) is provided to the user. Otherwise, the decoder receives the next scan, performs another decode attempt on that scan, and so on, until a completely decoded scan is achieved or no more scans are available.

Such a signal is then decoded according to the specific symbology into a binary representation of the data encoded in the symbol, and to the alphanumeric characters so represented.

Moving-beam laser scanners are not the only type of optical instruments capable of reading bar code symbols. Another type of bar code reader is one which incorporates detectors based on solid state imaging arrays or charge coupled device (CCD) technology. In such prior art readers the sides of the detector are typically smaller than the symbol to be read because of the image reduction by the objective lens in front of the array or CCD. The entire symbol is flooded with light from a light source such as lighting light emitting diodes (LED) in the scanning device, and each cell in the array is sequentially read out to determine the presence of a bar or a space in the field of view of that cell.

The working range of CCD bar code scanners is rather limited as compared to laser-based scanners and is especially low for CCD based scanners with an LED illumination source. Other features of CCD based bar code scanners are set out in U.S. Patent US-A-5,396,054, and in U.S. Patent US-A-5,210,398. These references are illustrative of the certain technological techniques proposed for use in CCD type scanners to acquire and read indicia in which information is arranged in a two dimensional pattern.

It is a general object of the invention to provide a laser scanner for bar code reading implemented on a semiconductor substrate.

It is another object of the present invention to mount light emitting and detecting elements on a miniature frame assembly capable of motion for effecting a scanning pattern.

It is still another object of the present invention to provide an array of lenses and/or an array of liquid crystal shutter elements adjacent to a semiconductor substrate that includes an array of light emitting and/or detecting elements.

It is yet another object of the present invention to provide an illumination light source for a bar code reader using a vertical cavity surface emitting laser diode.

It is still another object to enable auto alignment (i. e., do away with the focusing step in a manufacturing process) by using VCSEL arrays to achieve multiple focus.

It is yet a further object of the present invention to provide an integrated optical module, preferably although not necessarily for use within an optical scanner, which is not only robust in use but which can be manufactured in large quantities relatively inexpensively.

In accordance with these objects, the invention extends to an integrated optical module having a VCSEL which is spaced from a refractive or diffractive lens by a spacer of predetermined dimensions. During manufacture, the dimensions of the spacer may be chosen so that the laser beam is appropriately focused by the lens according to the desired application.

Such modules may conveniently be manufactured using wafer-scale processing and assembly technology. Using this approach, a wafer array of spacers is bonded within a sandwich formed by a wafer array of lenses on one side and a wafer array of VCSELs on a substrate on the other. Once the sandwich has been bonded or otherwise secured together, it may be cut up or diced into the required modules. Prior to dicing, the VCSELs making up the array on the substrate may be individually tested. Another approach is to dice the VCSELs initially, and then flip-chip mount them on the optical substrate. Electrical contacts can be established via solder bumps.

The sandwich may be diced into individual modules, each containing exactly one VCSEL, or it may be diced into larger units, each including a plurality of VCSELs in an array, for example for redundancy, multiple-ranging, time multiplexing, additional power or beam shaping.

It is a further object of the invention to provide a miniaturized scan engine or module for an optical scanner that is small, robust, and relatively inexpensive. It is a further object to provide a scan engine in which the current required for operation is reduced.

The general concept of the present invention, in one arrangement, comprises a scan engine, module or micro-mirror package in a sandwich structure consisting of a top cap, a bottom substrate, and a mirror in between. The scan engine may be manufactured in a batch process, for instance by micro-machining. The top cap and bottom substrate contain features to limit mirror travel so that the mirror hinges are protected against impact. To facilitate assembly, the sandwich may be laminated on the wafer scale, and then diced into individual cells. Electrodes and access means are provided both to actuate the mirror and to sense the mirror position. In addition, in some embodiments a transparent cover is provided to protect the mirror, with clear electrodes ei-

ther for electrostatic actuation of the mirror or for use in detecting mirror position. To minimise overall package height, thin wafers are used.

Each of the wafers is made of an appropriate material, such as plastics or silicon for the upper and lower wafers and silicon for the central wafer. Metal portions are added by printing, coating, or any other convenient means. For large scale manufacture, micromachining, microinjection moulding, compression-injection moulding and stamping are likely to be the most cost effective processes. The general approach described in Borgesen et al, Materials Research Society Symposium Proceedings, Vol. 323, 1994, may be used.

The lens wafer may be omitted, in some embodiments, with focusing of the VCSELs being provided by a suitable shaping (for example by etching or electron beam writing) of the VCSEL aperture itself, or of the mirror surface.

The invention also relates to a scan engine in which the mirror is actuated using the shape memory effect, for example in TiNi hinges. The amount of current needed to heat the hinges is reduced by providing an electrically conductive coating on those portions of the hinges which do not substantially contribute to the movement. Typically, this means coating a central portion of each hinge with a conductive coating, and leaving the end portions uncoated. The mirror may also be actuated (particularly but not exclusively in a cantilever arrangement) by applying heat to a bimetallic beam, or by electrostatic control. Piezo-electric control is also a possibility.

In keeping with the previously-stated objects, and others which will become apparent hereinafter, in one embodiment of the invention there is provided an integrated electro-optical system for reading indicia having parts of different light reflectivity, e.g. bar code symbols having alternating bars and spaces.

In one preferred embodiment, there is provided a method of reading indicia such as a bar code symbol by illuminating a field containing the indicia with a sequence of light spots by sequentially activating a plurality of separate light sources which are disposed on a semiconductor substrate; and detecting light reflected from the field to produce an electrical signal representing light of variable intensity reflected off the indicia.

Preferably, a bar code reader for reading such indicia includes a light source component for emitting one or more light beams; a light directing component for directing the light beam along a path toward the indicia; and a stationary photodetector component having a field of view and operative for detecting at least a portion of the light of variable intensity reflected off the indicia. An optical arrangement may be provided which functions to provide a series of independent scans of the indicia, each scan representing a different focal plane disposed exteriorly to the reader.

Preferably, a laser scanning device comprises a vertical-cavity, surface-emitting laser, mounted on a substrate and arranged to produce a multiple laser beam output, a scanning arrangement for effecting scanning by the laser beam, an optical arrangement for focusing the output on a target to be scanned, and a sensor for detecting the reflected light from the target.

The surface area of a VCSEL may usefully be used to support an optical component, such as a diffractive or refractive lens, directly in front of the diode surface. Mounting of the optical component may conveniently be effected during fabrication to achieve desired focusing. The laser may be operated only for short bursts in scanner applications, further reducing the power consumption of the VCSEL. As a result, the substrate for the VCSEL is likely to provide sufficient heat dissipation such that further head sinking of the laser is not required.

In one particular embodiment of the invention, a phased array of lasers may be arranged in groups that define focused scanning beams at differing positions. Alternatively, scanning may be done electronically by actuating a phased array of laser diodes to create the effect of a single scanning beam. These may be actuated selectively or in a predetermined automatic sequence. Thus, a multi-line scan may be produced, or the beam for two or more lasers may be developed to produce a beam spot of a given shape on a predetermined target plane, if that is the system requirement.

Scanning may also be effected by physically moving the laser about a field point or points. In both cases, therefore, especially in that of the phased array of lasers, the lower power consumption of the VCSEL is advantageous over prior art devices.

As used in this specification and the following claims, the term "symbol" is intended to be broadly construed and to cover not only symbol patterns composed of alternating bars and spaces, but also other patterns, as well as alphanumeric characters and, in short, any indicia having portions of different light reflectivity.

The invention further extends to any one ofthe following clauses 16-121, or any compatible combination thereof:

16. An optical scanner comprising:

(a) a light source for producing a light beam;
(b) a first substrate;
(c) a first mirror for receiving said light beam and for producing an intermediate scanning beam, said first mirror being mounted on said substrate for oscillation in a first direction;
(d) a fold mirror for receiving and reflecting said intermediate scanning beam; and
(e) a second mirror for receiving the reflected intermediate scanning beam and for producing an output scanning beam scannable in two directions, said second mirror being mounted to said substrate for oscillation in a second direction, different from said first direction.

17. An optical scanner according to Clause 16 wherein said light source is a vertical cavity surface emitting laser diode.
18. An optical scanner according to Clause 16 wherein said first substrate is substantially flat, and wherein said first and second mirrors are mounted to the first substrate in a side by side relationship.
19. An optical scanner according to Clause 16 including a second substrate, said light source and said fold mirror being mounted to said second substrate.
20. An optical scanner according to Clause 19 wherein said second substrate is substantially flat and wherein said laser and said fold mirror are mounted to the second substrate in a side by side relationship.
21. An optical scanner according to Clause 16 including a second generally flat substrate, said light source and said fold mirror being mounted to said second substrate; said first substrate being also substantially flat, said first and second mirrors being mounted to said first substrate in side by side relationship; and said first and second substrates being generally mutually parallel.
22. An optical scanner comprising:

(a) a light source for producing a light beam;
(b) a first scanner for producing from the light beam an intermediate beam scannable in one direction; and
(c) a second scanner for receiving said intermediate beam, said second scanner including an array of micromirrors, said micromirrors being arranged to scan in a direction different from said one direction, each said micromirror being driven synchronously with receipt of said intermediate beam, thereby producing an output beam scannable in two directions.

23. An optical scanner according to Clause 20 wherein said first scanner includes an oscillating mirror.
24. An optical scanner according to Clause 20 wherein said light source includes a vertical cavity surface emitting laser.
25. An integrated optical module for an optical scanner comprising a vertical cavity surface emitting laser for producing a laser beam, a lens positioned in said laser beam, and a spacer for defining a predetermined spacing between said laser and said lens.
26. A module according to Clause 25 including a substrate carrying said laser, and an optical element carrying said lens, said substrate being secured to said spacer and said spacer being secured to said optical element.
27. A module according to Clause 25 in which said spacer includes a plurality of spherical spacer elements.
28. A module according to Clause 27 including an optical element carrying said lens, said optical element having depressions therein, and said spacer including a plurality of spherical spacer elements received within said depressions.
29. A module according to Clause 25 including a wafer spacing element defining said spacer.
30. A module according to Clause 25 including a wafer optical element defining said lens.
31. A module according to Clause 25 including a wafer substrate defining said laser.
32. A module according to Clause 31 wherein said wafer substrate has a junction side and a rear side, said rear side being disposed towards said lens.
33. A module according to Clause 31 wherein said spacer includes a portion of said wafer substrate.
34. A module according to Clause 30 wherein said spacer includes a portion of said wafer optical element.
35. A module according to Clause 25 including a feedback photodetector for detecting laser intensity.
36. A module according to Clause 35 wherein said photodetector is disposed behind said laser, as viewed from said lens.
37. A method of manufacturing an integrated optical module for an optical scanner, comprising the steps of:

(a) providing a substrate array including an array of vertical cavity surface emitting laser diodes;
(b) providing a lens array including an array of lenses;
(c) securing said substrate array to said lens array to form a combined array; and
(d) dicing said combined array into integrated optical modules.

38. The method of Clause 37 including providing a spacer array and securing said spacer array between said lens array and said substrate array before dicing.
39. The method of Clause 37 wherein said dicing step includes dicing said combined array into optical modules, each of which includes exactly one vertical cavity surface emitting laser diode.
40. The method of Clause 37 wherein said dicing step includes dicing said combined array into optical modules, each of which includes an array of vertical cavity surface emitting laser diodes.
41. The method of Clause 37 wherein said securing step includes bonding said substrate array to said lens array.
42. The method of Clause 37 wherein said substrate array is a wafer.
43. The method of Clause 37 wherein said lens array is a wafer.

44. The method of Clause 38 wherein said spacer array is a wafer.

45. A scan module for an optical scanner comprising:

a substrate;
a frame secured to said substrate, and a suspended mirror mounted for oscillation on said frame;
a cover secured to said frame; and
a light source mounted to said cover for directing a light beam onto said mirror to produce a scanning light beam.

46. A scan module according to clause 45 wherein said substrate includes a mirror stop for protecting said scan module against jarring.

47. A scan module according to clause 45 wherein said cover includes a mirror stop for protecting said scan module against jarring.

48. A scan module according to clause 46 wherein said mirror stop is integral with said substrate.

49. A scan module according to clause 46 wherein said mirror stop is generally roof shaped.

50. A scan module according to clause 46 where said substrate and said frame together define a recess, said mirror being suspended across said recess, and the mirror stop being contained within said recess and behind said mirror.

51. A scan module according to clause 46 wherein the mirror stop carries electrodes for actuating oscillation of said mirror.

52. A scan module according to clause 46 wherein the mirror stop carries electrodes for detecting said mirror's position during oscillation.

53. A scan module according to clause 47 wherein the mirror stop is integral with said frame.

54. A scan module according to clause 47 wherein the mirror stop comprises a finger, cantilevered from said frame.

55. A scan module according to clause 54 wherein said cover comprises a generally rectangular cover frame having first and second opposing sides, and first and second fingers extending inwardly of said cover from said respective opposing sides.

56. A scan module according to clause 46 wherein said mirror stop includes detents for preventing said mirror from sliding across the mirror stop if said scan module is jarred.

57. A scan module according to clause 47 wherein said mirror stop includes detents for preventing said mirror from sliding across the mirror stop if said scan module is jarred.

58. A scan module according to clause 45 including first and second flexible mirror hinges for suspending said mirror on said frame, said hinges being flexible in torsion, to allow said mirror to oscillate.

59. A scan module according to clause 45 including at least one flexible hinge for suspending said mirror on said frame.

60. A scan module according to clause 59 wherein said hinge is of TiNi.

61 A scan module according to clause 59 wherein said hinge is of a shape memory alloy which moves between a first shape at a first temperature and a second shape at a second temperature.

62. A scan module according to clause 59 wherein said hinge has a first end portion secured to said frame, a second end portion secured to said mirror, and a central portion between said first and second end portions, said central portion carrying an electrically-conductive coating.

63. A scan module according to clause 45 including a mirror structure suspended on said frame by a cantilever beam, said mirror structure including said mirror and further defining an aperture; and a fixed pin received within said aperture for protecting said mirror structure against jarring.

64. A scan module according to clause 63 wherein said fixed pin forms part of said substrate.

65. A scan module according to clause 63 wherein said pin is a LIGA micromachined pin.

66. A scan module according to clause 45 including an optical element disposed between said light source and said mirror.

67. A scan module according to clause 46 wherein said optical element is a holographic optical element.

68. A scan module according to clause 66 wherein said optical element is a Fresnel lens.

69. A scan module according to clause 66 wherein said optical element is sandwiched between said frame and said cover.

70. A scan module according to clause 66 wherein said mirror defines a front surface, said optical element being secured to said front surface.

71. A scan module according to clause 66 wherein said optical element is disposed within the optical path of said scanning light beam.

72. A scan module according to clause 66 wherein said optical element is disposed outside the optical path of said scanning light beam.

73. A scan module according to clause 45 wherein said mirror is mounted for oscillation in two perpendicular directions.

74. A scan module according to clause 45 wherein said light source is a vertical cavity surface emitting laser.

75. A scan module according to clause 45 wherein said light source has an output surface, a detector film being disposed on said output surface which absorbs some of said light beam to provide a feedback signal.

76 A scan module according to clause 66 wherein said optical element acts as a beam splitter to direct a portion of said light beam onto a beam detector

to provide a feedback signal.

77. A scan module according to clause 76 wherein said beam detector is mounted to said frame.

78. A scan module according to clause 74 wherein said vertical cavity surface emitting laser includes a plurality of independently operable miniature lasers.

79. A scan module according to clause 78 including a lens array disposed in front of said miniature lasers.

80. A scan module according to clause 74 wherein said lasers are operated sequentially, thereby providing dynamic focusing.

81. A scan module according to clause 45 including a transparent cover sheet secured to said cover.

82. A scan module according to clause 81 wherein said light source is mounted to said transparent cover sheet.

83. A scan module according to clause 45 including an optical detector for detecting light reflected from an indicia to be read.

84. A scan module according to clause 83 wherein said optical detector is mounted to said cover.

85. A scan module according to clause 82 wherein said transparent cover sheet includes transparent electrodes for powering said light source.

86. A scan module according to clause 83 wherein said light source is mounted to said optical detector.

87. A scan module according to clause 45 wherein said light source falls within the optical path of said scanning light beam, thereby creating a shadow.

88. A scan module according to clause 87 including an optical detector for detecting light reflected from an indicia to be read and for providing an output signal representative of the position of said scanning light beam based upon a lack of reflections due to said shadow.

89. A scan module according to clause 82 wherein said transparent cover sheet includes transparent electrodes for actuating said mirror.

90. A scan module according to clause 82 wherein said transparent cover sheet includes transparent electrodes for detecting said mirror's position during oscillation.

91. A scan module according to clause 45 wherein said cover and cover frame have electrical contacts passing there-through.

92 A method of manufacturing scan modules for optical scanners, the method comprising the steps of:

(a) providing a substrate;
(b) providing a frame including a plurality of mirrors and a corresponding array of mirror frames, each said mirror being mounted to one said mirror frame of said array;
(c) providing a cover;
(d) securing said substrate to said frame, and said frame to said cover, to form a sandwich; and
(e) dicing said sandwich into individual scan modules.

93. The method of clause 92 including the step of bonding a transparent cover sheet to said cover prior to said dicing step.

94. The method of clause 92 wherein said substrate is of a plastics material.

95. The method of clause 92 wherein said cover is of a plastics material.

96. The method of clause 92 wherein said frame is of silicon.

97. The method of clause 96 wherein said step of providing a frame includes providing a frame in which said mirrors are secured to said mirror frames with TiNi hinges.

98. The method of clause 92 in which at least one of the said providing steps includes fabrication by micromachining.

99. The method of clause 92 in which at least one of the said providing steps includes fabrication by injection moulding.

100. The method of clause 92 in which at least one of the said providing steps includes fabrication by stamping.

101. The method of clause 92 in which at least one of the said providing steps includes fabrication by casting.

102. The method of clause 92 in which at least one of the said providing steps includes fabrication by extruding.

103. The method of clause 92 in which at least one of the said providing steps includes fabrication by coining.

104. The method of clause 92 in which at least one of the said providing steps includes fabrication by etching.

105. The method of clause 93 wherein said substrate, frame and cover are formed with alignment holes therein, the method including the step of inserting an alignment pin through said alignment holes prior to said bonding step.

106. A scan module for an optical scanner comprising:

a frame;
a mirror;
an elongate flexible shape memory hinge for suspending said mirror on said frame, said hinge having a first end secured to said frame, - a second end secured to said mirror and a central portion between said first and second ends; and
an electrically-conductive coating on said central portion of said hinge, leaving said first and second ends exposed.

107. A scan module for an optical scanner comprising:

a frame;
a suspended mirror mounted for oscillation on said frame;
a substrate secured to said frame including a first mirror stop for protecting said mirror against jarring;
a cover secured to said frame, said cover including a second mirror stop for protecting said mirror against jarring;
a light source mounted to said cover for directing a light beam onto said mirror to produce a scanning light beam.

108. A scan module for an optical scanner comprising:

a substrate;
a frame secured to said substrate, and a suspended mirror mounted for oscillation on said frame;
a cover;
a holographic optical element between said cover and said mirror; and
a light source mounted to said cover for directing a light beam onto said holographic optical element, said element directing said beam onto said mirror to produce a scanning light beam.

109. A scan module according to clause 45 including an additional mirror mounted for oscillation in a different direction from said suspended mirror, said scanning light beam being directed onto said additional mirror to effect scanning in two directions.
110. A scan module according to clause 45 wherein at least part of said substrate is a wafer.
111. A scan module according to clause 45 wherein at least part of said frame is a wafer.
112. A scan module according to clause 45 wherein at least part of said cover is a wafer.
113. An optical scanner according to clause 2 wherein said optical element is a micro-refractive optical element.
114. An optical scanner according to clause 2 wherein said optical element is a gradient-index optical element.
115. An optical scanner according to clause 8 wherein said array of optical elements includes a micro-refractive optical element array.
116. An optical scanner according to clause 8 wherein said array of optical elements includes a gradient index optical element array.
117. A scan module according to clause 66 wherein said optical element is a diffractive lens.
118. The method of clause 92 in which at least one of the said providing steps includes fabrication by injection-compression.
119. An optical scanner according to clause 1 in which the vertical cavity surface emitting laser has a shaped front surface which defines a lens.
120. An optical scanner according to clause 119 in which said front surface is electron-beam cut.
121. A method of manufacturing an integrated optical module for an optical scanner, comprising the steps of:

(a) providing a lens array including an array of lenses;
(b) patterning said lens array with electrical connections;
(c) securing to said electrical connection an array of vertical cavity surface emitting laser diodes to form a combined array; and
(d) dicing said combined array into individual optical modules.

The invention may be carried into practice in a number of ways and several specific embodiments will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a two-dimensional scanner according to an embodiment of the invention using two micromachined mirrors;
Figure 2 shows another embodiment using only one micromachined mirror but with an array of VCSELs that are turned on and off in a time-multiplexed manner;
Figure 3 shows another embodiment including an array of individual small mirrors;
Figure 4A shows yet another embodiment using two mirrors which are mounted on the same substrate but which scan in orthogonal directions;
Figure 4B shows yet another embodiment;
Figure 5 shows an exemplary micro-optics array;
Figure 6 shows another exemplary micro-optics array;
Figure 7 shows another exemplary micro-optics array;
Figure 8A is a schematic section through yet another exemplary micro-optics array;
Figure 8B is a top view of the micro-optics array of Figure 8A;
Figure 9 is a cutaway perspective view of a miniature scan engine in accordance with another embodiment of the present invention;
Figure 10 is a longitudinal section through the miniature scan engine of Figure 9, showing the electronics components in more detail;
Figure 11 illustrates the layered construction of the scan engine in one preferred form;
Figures 12A and 12B show alternative mirror stop arrangements;
Figure 13 illustrates a wafer bonding technique for

manufacturing miniature scan engine packages;

Figure 14 shows details of an alternative embodiment having a travel stop with teeth to prevent unwanted movement of the mirror;

Figure 15 shows a further embodiment for reducing the current required for shape memory actuated scan engines;

Figure 16 shows an alternative method of mounting the mirror;

Figure 17 shows yet another embodiment for two-dimensional scanning;

Figure 18 illustrates a hand held bar code reader suitable for incorporating any one of the described embodiments of the present invention;

Figures 19A and 19B show alternative micro-optics arrays to those shown in Figures 5 to 8;

Figure 20 shows two alternative perspective views of the arrangement of Figure 19B;

Figure 21 is a schematic section through a VCSEL;

Figure 22 is a more detailed section of the arrangement of Figure 19B;

Figure 23 is a schematic view from the rear of the arrangement of Figures 19B and 22;

Figure 24 illustrates a front plan view of a VCSEL and detector mounted on a torsional micromachined mirror;

Figure 25 illustrates an embodiment of a bar code scanner system; and

Figures 26a-26c illustrate alternative embodiments of a bar code scanner system.

Figures 1 to 4 show, in highly simplified and schematic form, some embodiments of scan engines/modules in accordance with the present invention. The modules shown are general purpose optical scanning modules which are suitable for a number of applications including, for example, bar code readers.

In Figure 1, light from a VCSEL (vertical cavity surface emitting laser diode) 156 is shaped and deflected by a refractive and/or diffractive optical element (DOE) 158. The DOE combines the functions of focusing, beam direction bending and some aberration or scan beam quality correction. The beam is then directed to a first mirror 162, scanning in the y direction, and then a second mirror 160, scanning in the x direction, to produce a two-dimensional scanning beam 161 which is directed via a window 1 in a housing 2 to an indicia (not shown) to be read. Reflected light from the indicia is detected by a photodetector (not shown) and digitized/decoded to interpret the indicia.

The order of the mirrors can be reversed, i.e. the first may scan in the x-direction and the second in the y-direction. Alternatively, a single 2D mirror can be used; 2D scanning may also be accomplished by a single cantilever structure.

Figure 2 shows a VCSEL array 166 and, in front of it, a DOE array 164. The VCSELs are turned on and off in a time multiplexed manner, thereby creating a beam 165 (or more properly a series of beams) which scans in the y direction. These beams are then incident upon an oscillating mirror 168, scanning in the x direction, to provide a two-dimensional scanning beam 169. This leaves a scanner housing 4 via a window 3 in a direction towards an indicia (not shown) to be scanned. Alternatively, reference numeral 166 may represent a laser array, and 164 an optical element and switching array. In this alternative, the laser array 166 is left on at all times, with the switching array 164 determining which beam or parts of the beam are allowed to pass. The switching array is sequentially actuated so that each optical element in the array in turn bends and/or focuses the beam. Since each optical element bends and/or focuses to a different extent, the resultant composite effect is of a single beam which scans in one direction.

Figure 3 corresponds generally to Figure 1, except that the second oscillating mirror 160 is replaced by an array 170 of smaller mirrors or "micro-mirrorlets". These smaller mirrorlets each scan in the same x direction, but are timed to be synchronous with the y scanning direction provided by the mirror 160. The advantage of smaller mirrors is higher frequency and possibly lower drive power. Again, the result is a beam 171 which scans in two dimensions. As before, the beam 171 leaves a scanner housing 6 via a window 5 towards an indicia (not shown) to be scanned.

Figure 4A shows yet another embodiment using two mirrors 172,174 mounted on a common substrate 176, but scanning in orthogonal directions. Light from a VCSEL 178 passes through a DOE 180 and is incident upon the first mirror 172. It is then reflected to a folding mirror 182 and back to the second mirror 174 to provide a two-dimensionally scanning outgoing beam 184. By mounting both mirrors 172 and 174 onto a common substrate, alignment problems may be reduced.

Figure 4B shows a practical embodiment of some of the ideas previously mentioned in connection with Figures 1 to 4A. The scanner assembly shown in Figure 4B has ceramic or plastic lower and upper substrates 180, 181, the distance between them being defined by spacers 182. Mounted on the lower substrate 180 is a VCSEL 183 with leads 184, a detector 185 with leads 186, a lower mirror 187, and interconnect pads 188. The upper substrate 181 includes collector optics 190, an upper downwardly-directed mirror 191 and a window 192 through which the outgoing scan beam passes. The electrical interconnect pads 188 provide electrical connections through the leads 184 to the VCSEL and through the leads 186 to the detector. Electrical control leads (not shown) are also provided to the lower mirror 187 and to the upper mirror 191.

In operation, the VCSEL 183 produces a laser beam (not shown) which is directed onto the upper mirror 191. This is mounted for oscillation as discussed in Figures 1 to 3 so that the reflected beam scans in the x direction. The reflected scanning beam then impinges upon the lower mirror 187, which is mounted for scanning motion

in the y direction. The resulting beam, scanning in both directions, passes out of the module through the window 192 towards an indicia (not shown) to be scanned. Light reflected from the indicia is collected by the collector optics 190 and is detected by the detector 185. The electrical output produced by the detector passes through the lines 186 to the interconnect pads 188 from which the signal may be passed on to a digitiser and if necessary to a decoder.

In all of the embodiments of Figures 1 to 4, the DOE may if desired be replaced by a holographic optical element or a micro-refractive optical element.

The embodiments of Figures 1 to 4 include, in each case, a VCSEL with an optical element positioned in front of it. Figures 5 to 8 show some exemplary embodiments showing how such VCSELs and optical arrangements may be fabricated using wafer-scale fabrication techniques. It will be understood, of course, that the embodiments described in Figures 5 to 8 are suitable for, but are not restricted to use with, Figures 1 to 4. The Figure 5 to 8 embodiments emerge from a recognition of the overall desirability of VCSELs in this application due to low operating power, aperture control, and the potential of wafer-scale fabrication. In addition, the applicants have discovered that if the VCSELs are appropriately positioned within a suitable optical arrangement, active focusing may in some circumstances be dispensed with.

Turning first to Figure 5, there is shown an upper wafer 1200, a central wafer 1202 and a lower wafer 1204. Each wafer may be manufactured using conventional wafer scale fabrication technology. To understand the typical size and shape of such wafer, reference should be made to Figure 13 which shows the overall configuration, although in connection with some other specific wafers to be described later.

The upper wafer 1200 comprises a two-dimensional micro-lens array having a large number of individual lenses 1201. The lenses may be either refractive lenses, diffractive lenses or both. The wafer may be formed by any convenient technique such as silicon micromachining, injection moulding, stamping, casting, extruding, electrostatic discharge or computer numerical control machining and so on. The material of which it is formed is not critical, but the lenses 1201 of course have to be of a material which can pass a visible VCSEL light beam. The central wafer 1202 acts as a spacer, and is conveniently fabricated from a semiconductor material such as silicon. The silicon is cut to the desired thickness and then etched with a two-dimensional array of apertures separated by spacing columns 1203. The apertures may be cut, punched or preferably etched through the wafer. The lower wafer 1204 is formed with a two-dimensional array of VCSELs 1205 to each of which wire bonds 1206 are attached.

Once the three wafers have been fabricated, they are aligned (for example using pins passing through alignment holes like the holes 128 shown in Figure 13) and then bonded together. The bonding may be carried out in any convenient manner including the use of precut or preformed adhesive films, liquid adhesives, solder bumping or anodic bonding. The bonded wafers are then diced into individual VCSEL/optics packages. For use in the embodiments of Figures 1, 3 and 4, each individual package will contain a single VCSEL and a single lens 1201, suitably spaced from the VCSEL by the spacers 1203. The height of the spacer 1203 is chosen according to the application to provide suitable focusing by the lens 1201. For the embodiment of Figure 2, the bonded wafers will be diced into larger blocks, each including within it a one or two-dimensional array of VCSELs and a two-dimensional array of lenses.

An advantage of wafer-scale fabrication, as described, is that the individual VCSELs 1205 in the lower wafer 1204 may be tested separately before dicing. A record is kept of the position of any VCSELs which do not operate correctly, and the corresponding packages including those VCSELs are discarded at the end of the procedure.

In a variant of the embodiment of Figure 5, the upper and central wafers could be combined into a single wafer which includes both the lenses 1201 and the spacers 1203. This could be achieved, for example, by the use of a precision glass or high temperature moulded plastics wafer having an array of through holes.

Figure 6 shows another possibility in which the central wafer 1202 is replaced with miniature glass beads 1301 which act as the spacer between the lens wafer 1200 and the VCSEL wafer 1204. Selected areas 1302 ofthe lens wafer are chemically etched into small cups or depressions into which the beads 1301 sit. The glass beads and the lens wafer 1200 are then fused, and the assembly is then bonded as described above to the wire bonded VCSEL wafer 1204.

In Figure 7, a modified VCSEL wafer 1404 is used, this being upside down as shown in the drawing when compared with the corresponding VCSEL wafers 1204 of Figures 5 and 6. The surface 1209 of the wafer which is now at the bottom (that is the junction side) is first bonded to a silicon detector wafer 1400, or to any other suitable substrate. Selected areas on which is now the upper surface 1208 of the VCSEL wafer are now thinned or etched down so that the laser energy emitted in the upper direction will no longer be absorbed by the substrate. The areas 1403 that are not thinned down become the spacers for the lens wafer 1200. The detector wafer 1400 comprises a two-dimensional array of individual detectors 1401, each detector being associated with one of the VCSELs on the VCSEL wafer. Once the sandwich has been bonded and diced into individual packages, the detectors 1401 provide feedback on the output intensity of its corresponding VCSEL. Wires 1409 provide the respective feedback signal for each of the individual detectors.

The detector wafer 1400 may include a row or an array of upstanding portions or "louvres" (not shown) to

create vignetting limiting the field of view. Preferably, such an arrangement may be used with an appropriate retro-collective optical system.

Yet another alternative is shown in Figure 8A and 8B, the former being a schematic section through another exemplary array, and the latter being a top view. In this embodiment, the upper wafer 1500 is formed on its upper surface with a macro-lens 1502 and on its lower surface with an array of micro-lenses 1503. These lenses 1503 correspond with an array of VCSELs 1504 on the lower wafer 1505. In operation, each of the micro-lenses expands the laser beam from its corresponding VCSEL, while the macro-lens 1502 then acts to collimate the beam. Such an arrangement offers significant flexibility, in that altering the micro-lens power can vary the beam focus profile, while appropriately shaping the micro and/or macro lenses allows the designer to achieve oval beam profiles which may be optimised for particular applications. Typically in this arrangement the macro-lens may be around 0.5 millimeters in diameter, with the micro-lenses around 50 micrometers in diameter.

A further alternative embodiment will now be described with reference to Figures 19 and 20. Figure 19A shows the VCSELs 1205 secured on the substrate 1204 and, between the VCSELs wire bonding pads 1901. Above the substrate 1204 is a lens wafer 1902. This layer may be fabricated in a manner similar to that disclosed for the fabrication of refractive microlenses in "Photolytic technique for producing microlenses in photosensitive glass", Borrelli et al, Applied Optics, Vol. 24, No. 16, 15 August 1985, or "Technique for monolithic fabrication of microlens arrays", Popovic, Applied Optics, Vol.27, No. 7, 1 April 1988. However, instead of being manufactured as a monolithic lens wafer, the microlens material is first patterned or alternatively precisely dispensed to cover only the VCSELs 1205 but not the wire bonding pads 1901. This is the state of manufacture shown in Figure 19A. The entire VCSEL wafer with the lensing material on it is then processed by heating or exposure to light. This process causes the lensing material to take up the form of individual lenses 1902', as shown in Figure 19B. It also causes the lensing material to harden in that configuration, with the lenses over the apertures of the VCSELs 1205, while leaving space between the VCSELs for the wire bonding pads 1901.

Figure 20 shows, very schematically, two possibilities for the array shown in Figure 19B. The first possibility, indicated generally by the numeral 2001, has the lenses 1902' and the wire bonding pads 1901 alternately spaced across the array in both directions. In an alternative arrangement, shown generally by the numeral 2002, the lenses 1902' and the wire bonding pads 1901 alternate in one direction but not in the other. In this last arrangement, the wire bonding pads form individual rows 2003, while the microlenses form their own series of individual rows 2004.

It will be understood that the types of two dimensional array shown in Figure 20 may be equally applicable for any of the arrays described, and in particular for the embodiments of Figures 5 to 8 and 21 to 23.

Yet another embodiment is shown in Figure 21 which shows, in more detail, a section through a VCSEL and its associated wafer. The VCSEL 2100 includes a mirror stack 2102 and, in front of that, a patterned diffractive focusing lens 2104. The diffractive lens may be produced directly on the aperture of the VCSEL by electron beam writing or by other ion milling methods after the VCSELs are fabricated. The same diffraction pattern may alternatively be generated by an extra masking step in the VCSEL fabrication process. The VCSEL itself is located within the wafer substrate 1204, the confinement region being indicated by the hashed area 2106. Adjacent the VCSEL aperture are wire bonding pads 2108 to which electrical connections 2110 may be bonded. In operation, lasing commences on receipt of a signal via the wire bond 2110, with the refractive lens 2104 creating a focused outgoing laser beam 2112.

Figures 22 and 23 show a further alternative arrangement. Here, a microlens wafer array 2206 consists of an array of individual lenses 2208 connected by a flat lens substrate 2210. The rear of the lens array is patterned with the desired electrical interconnections 2212, allowing for bonding of wire bonds 2214. VCSELs 2200 are positioned behind the lenses 2208, and are secured to the electrical interconnections 2212 by flip-chip bonding 2216. Figure 23 shows the view from the rear, immediately behind one of the VCSELs 2200.

The manufacture of the embodiment of Figures 22 and 23 is quite straightforward. First, a VCSEL wafer is tested and defective devices are marked to be discarded later. The wafer is then diced into individual VCSELs or into small arrays of VCSELs. The microlens wafer 2206 is fabricated with the lenses 2208 being appropriately spaced to accommodate the VCSELs and the wire bonding pads. The lower surface of the wafer 2206 is then patterned with the desired electrical interconnections 2212. Next, the VCSELs 2200 are robotically picked and placed onto the lens wafer, in the appropriate position, and flip-chip bonded 2216. Wire bonding 2214 to the pads on the lens wafer is then performed to provide electrical access to the VCSELs. The lens wafer is then diced into individual pieces.

Figures 9 and 10 show, also in highly simplified and schematic form, a scan engine/module in accordance with a further embodiment of the present invention. It is to be understood that the purpose of these Figures is merely to illustrate one possible arrangement of the features; further details of the individual features will be discussed below in connection with the other drawings.

The miniature scan engine shown in Figures 9 and 10 has a base or substrate 10 to which is bonded a generally rectangular mirror frame 12 for supporting a mirror 14. The mirror 14 size may typically be between 1 and 3 mm. The mirror is suspended between opposite edges 13a, 13b of the frame by TiNi (or silicon) hinges 16a, 16b.

Because the hinges are slightly flexible in torsion, the mirror is free to make slight oscillations about the hinge axis, in the directions indicated by the arrows 18.

Supported on a subsidiary frame 20 above the mirror 14 is a holographic optical element (HOE) 22 and/or a Fresnel lens 24. Supported on an upper frame 30 is an upwardly-facing photodetector 26 and a downwardly-facing laser 28. The photodetector 26 is provided with a cut-out portion 32 in a direction perpendicular to the axis of the hinges 16a,16b. Alternatively, there may be two separate detectors with a gap in between; or the beam may be deflected past one side of a single detector.

In operation, the laser 28 produces a light beam 34 which is conditioned and directed towards the mirror 14. A mirror driver 34 (Figure 10) causes the mirror rapidly to oscillate in the direction of the arrows 18, so producing a reflected scanning beam 36. This again passes through the HOE 22 and out of the scan engine via the cut-out portion or slot 32. The resultant scanning beam 38 is directed to an indicia (not shown) to be read. Light 40 reflected from the indicia is detected by the photodetector 26, and a corresponding signal is sent to the digitizing and decoding electronics 42, these electronics including a microprocessor or CPU 44. The microprocessor provides an output signal on a line 46 representative of the characters or other information which are encoded by the indicia being read. A signal is also provided on a line 48 to mirror control electronics 50, the mirror control electronics controlling the mirror driver 34. A further signal on a line 52 allows the microprocessor to control operation of the laser 28.

Sensing electrodes 54 may detect the position of the mirror and provide a feedback signal to associated electronics 56. These may provide feedback control signals to laser control electronics 58. It will be understood, of course, that the electronics may be positioned anywhere convenient on the module, and not just in the positions shown.

We now turn to a more detailed description of the various components illustrated in Figures 9 and 10. The laser 28 will normally be a laser diode, and is preferably a vertical cavity surface emitting laser diode (VCSEL). The packaging advantage of using a VCSEL instead of a more conventional edge-emitting visible laser diode (VLD) is that VCSELs can naturally be placed on a flat surface emitting the beam from their opposite surface as shown in the drawings.

There are various possibilities for providing accurate laser power control, in addition to or instead of the feedback loop 56,58 shown in Figure 10. Alternatively, the HOE may incorporate a beam splitter to direct a small proportion of the output beam towards a detector 60 on the mirror frame 12. Finally, another laser on the VCSEL chip (covered by a detector) could be used to monitor the change in power output of the VCSEL with temperature, and used to adjust the drive current. The VCSEL can in principle be designed to be self-compensating of temperature change.

The VCSEL chip may contain several independently operable lasers. Each laser may have active areas of a different size so that a single focusing lens such as the HOE 22 can provide beams with different working ranges. Alternatively, a miniature lenslet array can be placed on top of the VCSEL chip, changing the divergence of each laser slightly so that a common focusing lens 22 can generate beams with different working lenses. The lasers may be operated sequentially, thereby obtaining dynamic focusing.

The VCSEL chip may be secured to the upper frame 30, as shown in the drawings, or alternatively it could be secured directly to the underside of the photodiode 26. Provided that the spacing within the scan engine can be well defined, and the HOE 22 suitably chosen, there may be no need to dynamically focus the laser. To that end, a spacer 62 positioned between the laser and the lens 24 may locate the laser to an accuracy of better than 20 micrometers, thereby achieving repeatable and accurate focusing without the need for adjustment. Another spacer 66 defines the spacing between the HOE and the mirror. The laser beam 34 is deflected and focused towards the mirror 14. In an alternative embodiment (not shown) one or both of these may be replaced by a conventional lens. In addition, in other embodiments it may not be necessary for the scanning beam 36 from the mirror to pass back through the HOE 22. In yet another embodiment (not shown), the lens 24 and the HOE may be combined into a single HOE. Alternatively, or in addition a diffractive optical element may be etched onto the mirror surface, or separately attached to the mirror surface, thereby eliminating the need for the optical elements 22 and/or 24. A yet further possibility is to mount a separate refractive lens 64 onto the mirror surface. By mounting the focusing lens 64 directly onto the scanning surface, it is ensured that the light has to travel through the lens twice; accordingly, the focusing effect of the lens is effectively doubled, so reducing the power of the lens. A negative lens will increase the scan angle. if desired. Additional optics may be provided, as necessary, to correct the geometrical "smiley" effect. Another grating could also be provided to straighten out the deflection effect.

If it is thought desirable to shape the beam profile, additional apertures (not shown) may be provided. Where an elliptical beam is required, either the VCSEL aperture may be made elliptical, or the HOE could instead be used to obtain the appropriate shape. Alternatively, an aperture (not shown) could be used to shape the outgoing beam. Two lasers may be located one above the other on the same chip to provide an elliptical beam; this approach can also increase the laser power.

The cutout portion or slot 32 through which the outgoing beam 38 leaves the scan engine may be etched out from the photodiode 26. Alternatively, two photodiodes may be used leaving the necessary aperture between them for the beam to leave the module; or there

could be one photodiode placed to one side of the beam.

While the photodiode 26 is shown as part of the scan engine in Figures 9 and 10, this is not essential and the photodiode can, if desired, be housed independently in a separate receiver front end. The receiver front end (not shown) consists of the photodiode, an optical filter, an optical apparatus to limit the field of view of the receiver, and the necessary electronics. The optical filter may be coated directly onto the photodiode surface. The field of view of the detector needs to be limited in order to reduce the ambient light reaching the photodiode, and this may be achieved in several ways. Firstly, a focusing lens may be placed in front of the receiver, which collects the scattered light over a well defined solid angle. Baffles around the photodiode may also be used to limit the detector's field of view. Alternatively, a miniature louvre filter may be employed to limit the numerical aperture of the receiver. The use of a louvre filter greatly reduces the size of the device, since it may be thinner than 1 mm, and may be directly mounted onto to the diode-filter assembly. The receiver electronics may be placed on the rear side of the photodiode, or may be placed in an electronics package 68 (Figure 1) on the side of the scan engine.

It will be recalled that Figures 9 and 10 are purely schematic. Figures 3 and 4 show in more detail how a practical embodiment of the invention may be constructed in its preferred form. As Figure 4 shows, the scan engine package is preferably built up as a sandwich using wafer technology. The package includes, in order, a wafer substrate 100, a wafer mirror frame 102, and a wafer cover 104. The wafer cover 104 may include or may have attached to it a transparent cover sheet 106.

The wafer substrate 100 includes a substrate frame 108 within which there is a roof-like stop member 110, the purpose of which is to prevent excess movement of the mirror, for example when the package is dropped. The stop member also includes control electrodes 112 and position detecting electrodes 114 for controlling and detecting movement of the mirror. The electrodes are preferably through-wafer coated electrodes, but could instead be pins inserted into the wafer. Alternatively, the electrodes may be printed on the upper surface of the stop member 110, with appropriate electrical connections (not shown) to the control electronics. In the recess (not shown) beneath the stop member there may be contained the necessary control electronics and/or printed circuit boards.

Bonded to the upper surface of the frame 108 is the frame 12 of the wafer mirror frame 102. This carries the mirror 14 on hinges 16a,16b as previously discussed. Bonded to the frame 102 is the wafer cover 104 which includes cantilevered spring-board like mirror stops 116. These stops extend inwardly from opposing edges of the wafer cover and are positioned immediately above the hinges 16a,16b so as to extend out over parts of the mirror. It should be noted that these stops are not shown in Figures 9 and 10. If the device is dropped, the stops 116 along with the stop member 110 prevent breakage by limiting mirror travel and the amount of stretching of the hinges 16a,16b.

Above the wafer cover 104 is the transparent cover sheet, to which is mounted the VCSEL 28. The electrical connections to the VCSEL are provided by wire bonds to miniature pads (not shown) on the cover sheet, immediately beneath the VCSEL. These in turn are connected to pads 118 at the edge of the cover sheet by transparent conductors 120, 122. It will be appreciated, of course, that the scanning beam 38 (Figure 9) passes out through the transparent cover sheet and will accordingly be partially intercepted by the VCSEL chip 28. However, in view of the chip's very small size (approximately 50 micrometers square) it will have minimal practical effect on the beam quality. Indeed, the very slight discontinuity in the beam may be detected within the incoming reflected light 40, and may be used to provide a feedback signal which tracks the beam movement.

The transparent electrodes may in some embodiments be used instead of or together with the electrodes 112 for driving the mirror. Alternatively, they may be used instead of the electrodes 114 for sensing mirror position.

In an alternative embodiment (not shown) the VCSEL may be placed off-centre on the cover sheet 106, thereby reducing its effect on the outgoing beam. However, if the chip were to form a large incident angle with the outgoing beam it would tend to cause a "smiling" effect in the beam, which is undesirable.

In operation, power and/control signals are transmitted through the sandwich by means of appropriate through-wafer electrodes shown schematically at 124 and 126.

Figures 12A and 12B show two preferred alternatives for the configuration of the wafer substrate 100. The arrangement in Figure 12A corresponds generally although not precisely to that shown in Figure 11, in that it incorporates a roofed stop member 110' for limiting the extent of travel of the mirror 14. Electrodes are positioned on the slanted floor. In the alternative arrangement of Figure 12B, the stop is replaced merely by an upstanding rib 110," with the electrodes 112,114 being coated onto the flat surface of the substrate on either side of the rib. While the embodiment of Figure 12A is somewhat more efficient in use, the embodiment of Figure 12B is cheaper to manufacture.

The sandwich structure best illustrated in Figure 11 may be put together individually for each new scan engine being manufactured. However, this is a rather costly process and Figure 13 illustrates an alternative approach in which three large scale wafer arrays are first fabricated, then bonded together, and finally diced or cut up into a plurality of individual packages. In Figure 13, the upper wafer 1104 represents a repeating array of wafer covers 104, the middle wafer 1102 a repeating array of mirror frame wafers 102 and the lower wafer 1100 a repeating array of wafer substrates 100. Prior to bond-

ing and dicing, the wafers are aligned by means of pins (not shown) which pass through respective alignment holes 128 in each of the wafer arrays. Alternatively, infra-red alignment marks may be incorporated on the wafers, in which case the pins may be eliminated.

The wafer arrays may be fabricated by a variety of techniques, such as silicon micromachining, injection moulding, stamping, casting, extruding, electrostatic discharge or computer numerical controlled machining, etch-form-and-coining, and so on. The bonding may be realised using a variety of techniques including precut or preformed adhesive films, liquid adhesives, solder bumping, thermal or anodic bonding, or any other technique commonly used in the industry.

For the lower wafer array 1100, which will ultimately in the preferred embodiment form the wafer substrate, micromachining, microinjection moulding, and a combination of etching and metal forming are the preferred technologies, although stamping is another possibility. The substrate is preferably of an appropriate resin material, such as polyetherimide, polycarbonate, polyester or styrene based resins. In order to prevent the accumulation of static charges on the plastics, impregnated electrically conductive particles may be used. The electrodes on the lower array 1100 may be coated or printed. Depending upon the exact configuration ofthe wafer substrate, contact masking may also be possible. Electrical access to the electrodes may be provided by printing or coating the electrodes through-wafer, using vias, with the patterns imaged on both sides of the substrates. Alternatively, rectangular pins may be inserted through-wafer during or after the plastic moulding process. These pins become the electrodes themselves. If the electrodes are printed only on one side of the wafer, then wire bonds may be routed through to exposed frame areas where external electrical contacts can be provided. The mirror stops on the wafer substrate may be provided by an etched BeCu plate, the raised mirror stop portions being created by coining. This plate then can be laminated onto a PC board with actuation and pick-up electrodes. Alternatively, the plate may be laminated with an etched Kapton spacer disk.

The central wafer array 1102 is preferably of silicon with TiNi hinges 16a,16b.

The top wafer array 1104 is preferably of a plastics material, and may be formed in the same way as the bottom wafer array 1100.

In addition to the upper array 1104, a transparent top sheet (not shown) may be provided which will eventually form the transparent cover sheets 106 (Figure 11). A transparent top sheet not only protects the mirror from foreign objects in use, it also provides protection from debris and molten resin or silicon during wafer dicing. As already discussed in conjunction with Figure 11, transparent electrodes may be deposited on this cover sheet.

Turning now to Figure 14 there is shown an alternative stop arrangement that may be used in substitution for the stops 110,110',110" of Figures 11 and 12. In this variation, a stop member 130 is formed with a plurality of teeth 132. If the scan engine is dropped, the hinges 16a,16b are likely to stretch until the mirror 14 hits the stop 130. This in itself may be enough to prevent the hinges being damaged, but if the mirror hits the stop at an oblique angle it may continue to slip and slide across the stop until the hinges become damaged. In this variant, the teeth 132 prevent this slippage from occurring.

The teeth 132 could in some configurations be replaced by elongate ridges or indentations in the stop, and they may be provided on all of the stops or only on some of them, as required. The stops with teeth, ridges or indentations may be realised by micro-machining, etching, machining, grinding, moulding, stamping, sanding, plating, electro-forming or any other appropriate process. The mirror stop could also in an alternative embodiment, be integral with the mirror itself or with the moving mirror assembly.

It will be understood that the mirror 14 may be oscillated using any appropriate type of driver 34 (Figure 10). Suitable drivers include electromagnetic and electrostatic drivers, along with drivers which use the shape memory properties of the TiNi hinges 16a,16b. This last approach will now be described in more detail with reference to Figure 15.

Figure 15 is a top view of the mirror frame wafer 102 showing the mirror 14 suspended on the frame 12 by means of TiNi hinges 16a,16b. The shape memory effect relies on the fact that shape memory alloys such as TiNi return to their high temperature (austenite) shape when heated above a critical temperature, usually 60° to 70° centigrade; this can be changed by altering the schoichiometry of the Ti and Ni composition. In order to obtain two-way shape memory, which is necessary for the mirror 14 to oscillate between two different positions, the shape memory alloy needs to be "trained" to have a cold (martensite) shape as well.

The mirror is actuated by applying a sine wave, square wave or other periodic signal through the hinges. The hinges become resistively heated when the current is on, and lose heat when the current is off. When the square wave is applied at the device's resonant frequency, the mirror oscillates back and forth about its torsional axis as the hinges are changing shape between their austenite and martensite states.

It is believed that most of the shape change occurs at the ends of the hinges, where they meet the frame and the mirror, and where large stress concentrations build up. However, the hinges become heated uniformly along their length which is inefficient since most of the heat generated in the central portion of each hinge is not instrumental in the shape change. Accordingly, to improve efficiency, each hinge has its central portion 134,136 coated with a thin layer of an electrically conductive material. This avoids heating that portion of the hinge, and concentrates heating at the hinge ends

where most of the shape change is taking place. In Figure 15, the end portions of the hinges 138-144, which are left uncoated, are shown in grey. The hinges may be rounded at the corners to reduce stress concentration and improve life.

Even where electrostatic actuation of the mirror is preferred, the shape memory property of the TiNi hinges may also be used. When the device is dropped, the TiNi hinges may stretch (strain) by about 3% to 4%, but their original shape can be recovered by passing through the hinges a short pulse of electric current. This heats up the hinges, and as they return to their ustenite state, they reshape themselves back to their original form. The current pulse may, in the preferred embodiment, last for about 50 m.secs., and be of around 100 mA.

It is not essential for the mirror to be suspended between torsional hinges, as previously described. Other modes of mounting the mirror for oscillation may be equally useful, and all are intended to be encompassed within the scope of the present invention. One preferred alternative mirror mounting arrangement is shown in Figure 16.

In the cantilever-type arrangement of Figure 16, the mirror 14' is mounted for oscillation on the frame 12 by two cantilever beams 146. The mirror is formed with an extension 148 within which is etched or otherwise formed an elliptical hole 150. A pin 152 is received within the hole and served to limit mirror travel, in the event that the device is dropped, both in the x and y directions. It also limits twisting movement of the mirror about the x axis. Finally, the pin also serves as an over-travel stop in the up and down (z) direction, the desired motion of the mirror as the beams 146 flex slightly in normal operation.

The pin 152 is desirably fabricated by the LIGA micromachine process. This process is very well known to those familiar with micromachining technology, and will accordingly not be described here. The mirror may be oscillated by any convenient means, including electromagnetically, electrostatically, bimetallically, or by means of the shape memory process. The mirror 14" (and indeed the mirror 14 shown in Figure 9) is desirably rectangular, but could also be square, circular or elliptical. Laser speckle may be reduced by the use of several lasers.

The present invention relates not only to one-dimensional but also to two-dimensional scanners, and there is shown in Figure 17 a schematic sectional representation of such a scanner.

In the embodiment of Figure 17, the reflected beam 36 from the mirror 14 is incident upon a second mirror 152 which is scanning in a direction orthogonal to that of the mirror 14. Accordingly, the outgoing beam 154 scans in two separate directions. The mirrors 14,152 have different resonant frequencies, and the frequency of the second mirror 152 may be greater or less than the frequency of the other mirror 14.

It will be noted in the Figure 17 embodiment that, in contrast with Figure 11, the reflected beam 36 entirely misses the HOE 22 and/or the Fresnel lens 24. In an alternative arrangement (not shown) either or both of the beams 36,154 could be shaped and/or deflected by a holographic optical element.

The scan engine of the present invention may be incorporated into any desired portable or fixed scanning system, such as a bar code scanner.

Figure 18 illustrates a highly simplified embodiment of one type of bar code reader that may utilise any of the scan engines described. In one hand-held embodiment, shown in Figure 18, a housing 1155 includes an exit port 1156 through which an outgoing laser light beam 1151 is directed to impinge upon, and to be scanned across, symbols 1170 located exteriorly of the housing. The device may also find application in pen-scanners, mice, telephone scanners, PC-cards and so on.

The hand-held device of Figure 18 is generally of the style disclosed in U.S. Patent US-A-4,760,248 or in U.S. Patent US-A-4,896,026, and is also similar to the configuration of a bar code reader commercially available as part number LS 8100, LS 2000 or LS 3000 from Symbol Technologies, Inc. Alternatively, or in addition, features of U.S. patent US-A-4,387,297 or U.S. Patent US-A-4,409,470, may be employed in constructing the bar code reader unit of Figure 18.

Referring to Figure 18 in more detail, an outgoing light beam 1151 is generated in the reader, usually by an electro-optic device of the present invention, and directed to impinge upon a bar code symbol disposed on a target a few centimetres or inches from the front of the reader unit. The outgoing beam 1151 is scanned in a scan pattern, and the user positions the hand-held unit so this scan pattern traverses the symbol to be read. Reflected and/or scattered light 1152 from the symbol is detected by a light-responsive device 1158 in the reader unit, producing serial electrical signals to be processed and decoded for reproducing the data represented by the bar code. As used hereinafter, the term "reflected light" means reflected and/or scattered light.

In a preferred embodiment, the reader unit is a gun shaped device having a pistol-grip type of handle 1153. A movable trigger 1154 is employed to allow the user to activate the light beam 1151 and detector circuitry when the user has positioned the device to point at the symbol to be read. A lightweight plastic housing 1155 contains the laser light source 1146, the detector 1158, the optics 1157, 1147, 1159, and signal processing circuitry including a CPU 1140 as well as power source of battery 1162. A light-transmissive window 1156 in the front end of the housing 1155 allows the outgoing light beam 1151 to exit and the incoming reflected light 1152 to enter. The reader is designed to be aimed at a bar code symbol spaced from the symbol, i.e., not touching the symbol or moving across the symbol.

The reader may also function as a portable computer terminal, and include a keyboard 1148 and a display

1149, such as described in the previously noted U.S. patent US-A-4,409,470.

Referring now to Figure 24, there is illustrated a top plan view of a device structure according to another embodiment including an integrated GaAlAs VCSEL laser diode device 2410 mounted on a silicon substrate 2412, the device and substrate being collectively referred to herein as "the laser arrangement 2414". The laser arrangement 2414 is suspended within a miniature frame assembly 2416 by a pair of TiNi torsional hinges 2418 which are secured to the substrate 2412 and to a respective opposite face of the frame 2416.

Electrical contacts 2420, 2420' pass along each hinge 2418. One contact 2420 is connected to the laser diode 2410, providing power from a remote source.

The active area of the VCSEL is well protected by its less sensitive surfaces and it is possible to wafer-bond the substrate 2412 with the device 2410. The unwanted semiconductor areas (both Si and GaAlAs) can then be etched away in order to define the centre isle.

While the device of Figure 24 is illustrated as being suspended in the frame by a torsional hinge on either side, the invention could equally be implemented in the form of a cantilever structure as well. The actuation mechanism for physically moving the device can be electrostatic, bimetallic, shape memory, piezo-electric, magnetic or any other known form by which sufficient movement can be imparted in a sufficiently smooth and appropriate way. It can also be mounted on more conventional and taut band elements, mylar or other moving substrates. A lens can be provided on top of the VCSEL for focusing. The lens can be diffractive optics and be "wafer bonded" to the VCSEL.

Referring now to Figure 25, which shows the laser arrangement 2514 of Figure 24 located in a housing 2529 or a bar code reader 2531, the laser diode 2510 produces a diverging light beam which is collimated by a lens array 2524 mounted directly on or closely adjacent to the emitting surface of the device. A diffuser 2526 could be used in the path of the collimated beam in the embodiment in which the VDSEL is to produce uniform illumination. If one nears the beam, it is preferably collimated and not diffused. If the beam is diffused, then it is used only to illuminate the target and we need a CCE array for diffusion.

The laser light beam output, either collimated or diffused, passes through a window 2527 in the housing 2529 of the scanner apparatus 2531 and is incident upon a target 2528 including a bar code symbol to be read. The laser arrangement 2514 is rotated about its torsional hinges 2518 which produces a linear motion of the static light beam which scans the bar code symbol 2528. Light reflected from the bar code is detected by a photodetector 2530, and the variation in intensity of the detected light is then digitized and applied to a decoder of conventional arrangement. Typical movement of the laser arrangement 2514 will sweep an included angle of about 40° to perform the scan.

By using a VCSEL to illuminate the bar code target, an illuminating light source is realized with significantly less heat generated than in prior art devices. In this case, the beam is not scanned, but the receiver will be either a CCD or CMOS detector array.

While the bar code reader 2531 is depicted in Figure 25 as a fixed installation it may, in other embodiments, take other various forms. For example, it could be embodied as a trigger-operated scanning gun such as has been described in connection with Figure 18.

Referring back to Figure 24 in addition to the VCSEL being integrated on the surface of substrate 2412, which acts as a "scanning mirror," the remaining portion of the mirror 2412' and frame 2412" can be made into a photodetector sensor element or array. The photodetector on the mirror is of the retroreflective type, since the mirror is always turning in the direction of the scan beam. The detectors 2412" on the frame are stationary, and of the non-retroreflective type. The frame area can be increased by filling in the empty spaces near the torsional hinges that support the mirror.

Referring next to Figures 26,26b and 26c, alternative embodiments of the invention are shown. Figure 26a illustrates the combination of a laser diode 2640, which may be a VCSEL array, together with a suitable lens 2641, for collimating or focusing the light emitted from the laser diode 2640, and a liquid crystal array 2642. It is generally known, for example from U.S. Patent US-A-5,071,229, to provide a variable focal length lens constructed of a material having the electro-optic effect such as liquid crystals, liquid crystal polymer, PLZT, etc., light blocking means variable in aperture size, and in general means for changing the focal length of the variable focal length lens in synchronization with variations of the aperture size of the light blocking means. Thus, it is known that the brightness of visual field and the depth of field according to the focusing and the distance to the object can be controlled with a liquid crystal device. An electromagnetic stop apparatus such as a liquid crystal stop has been proposed in the prior art to interlock the focusing adjustment of the imaging lens with the variation of the stop diameter of the imaging lens by the combination with the variable focusing lens such as a liquid crystal lens. A conventional example of the electro-optic stop apparatus is described in Japanese Publication JP-A-59-156219.

The present embodiment may also utilize the LC array 2642 to perform scanning of the bar code symbol 2643 by means of sequentially, selectively activating individual elements of the LC array 2642 to direct the light emitted from the lens 2641 into a predetermined pattern so as to form a path on the target symbol 2643. The light reflected from the symbol will be detected by a discrete sensor 2644, as is conventional in prior art bar code reading systems. Reference here is made to U.S. Patent US-A-5,258,605, and in particular to Figure 20 therein.

An alternative embodiment shown in Figure 26b utilizes a light source 2647 to illuminate the bar code sym-

bol 2643. The LC array 2642 is now operative in connection with a detector array 2645 which images a field of view, so that the LC array selected and defines the portion of the field of view which is imaged upon the array 2645. A corresponding array of focusing lens, such as the array illustrated in U.S. patent US-A-5,345,336, may be used in connection with the array so that specific detector elements in the array 2645 are associated with a lens element of a specific optical characteristic (e.g., focal length, aperture, polarization, filtering, etc.). The matching of detector elements and lens elements may be used to more accurately image the symbol 2643 on the array 2645 in circumstances when the symbol 2643 is situated at an arbitrary or unknown distance from the array, or the plane of the symbol is positioned in a skewed manner with respect to the plane of the array.

Thus, this embodiment of the present invention provides a bar code reader for reading a symbol located at a distance from the reader, including an array of groups of reading elements, each group having na associated predetermined operating focal distance; an array of selectable liquid crystal elements disposed adjacent to the array of reading elements, at least one liquid crystal element corresponding to each group of reading elements; and means for activating a selected liquid crystal element as so to select a corresponding group of reading elements for transmitting light through corresponding selected element, whereby the reader is operated at a predetermined selected operating focal distance.

In lieu of using a liquid crystal matrix, as shown in Figures 26a and 26b, it is also possible to use an array of miniature mirrors in its place in the path of the outgoing or incoming light beam. By selectively activating individual rows of such mirrors (or predetermined ones of such mirrors in a sequential pattern), one can "select" either specific light source elements (such as in a VCSEL array of light sources) or detector elements (such as in the array 2645) depending upon the type of scanning pattern (or field of view imaging) one wishes to implement. Deformable mirror devices, (hereinafter "DMDs") such as those of Texas Instruments as described in the article "IBM, TI Announce Better Ways to Manipulate Light Signals," IEEE Institute, November 1989, Vol. 13, No. 11 may also be used in place of, or in addition to, the liquid crystal matrix. See also U.S. Patents US-A-5,256,269, US-A-5,083,857 and US-A-4,441,791. As noted in such references, DMDs depend on the same sort of address circuitry as dynamic RAMs to access an array of electrodes, which lie on the chip's surface and control the mirror pixel elements poised above them. DMDs also have both analogue and digital capability. For an analogue application, applying charge to one of the two address electrodes rotates a mirror pixel in that direction; increasing the voltage increases the angle the mirror rotates. The applications envisioned here employ full rotation in one direction or the other.

Figure 26c is an enlarged view of still another embodiment of the invention similar to that of Figure 26a. Figure 26c shows a two-dimensional array 2633 of VCSEL lasers 2610 arranged in rows and columns 2632 and disposed in a common substrate 2634. An array of lenses 2635 are similarly arranged in the path of the output of the device. While the array of lenses 2635 is shown remote from the VCSEL in Figure 26c, they may also be advantageously mounted directly on the laser beam emitting substrate as in Figure 25. Reference may be made to U.S. Patent US-A-5,345,336 as an example of one implementation depicting a lens array disposed closely adjacent to a semiconductor light source. Another lens 2638 is disposed in the beam path to focus each individual beam at different distances D_1, D_2 and D_3, for example.

In this embodiment, there is no physical movement of the device to effect scanning, but in other embodiments an array may be located on a moving substrate. In Figure 26, the effect of scanning is created by sequential excitation of the VCSELs 2610 in the columns of the array. By this sequential excitation the equivalent of a single scanning beam is created such that a bar code 2637 is swept in order for a detector 2638 to be able to pick up the variations of intensity of light reflected therefrom for decoding in the conventional way.

The invention may be carried out with various types of VCSEL devices, those incorporating II-VI or more especially III-V Group Compound semiconductor materials layers preferred.

The array of lenses 2635 is, in one embodiment, arranged to provide a single scanning beam effect with one plane of focus. However, the array of lenses 2635 can also be designed to create a sequence of beams being focused at different planes. In this case the focal plane of interest could be selected manually or be part of an automatic sequence, which repeats until the decoding apparatus acknowledges receipt of successfully decoded information. Thus, the present invention also provides a bar code reader for reading a symbol located at a distance from the reader, comprising an array of groups of reading elements, each group having an associated predetermined operating focal distance; an array of selectable liquid crystal or DMD elements disposed adjacent to said array of reading elements, at least one liquid crystal or DMD element corresponding to each group of reading elements; and means for activating a selected liquid crystal or DMD element so as to select a corresponding group of reading elements for transmitting light through corresponding selected element whereby the reader is operated at a predetermined selected operating focal distance.

Of course, the present invention can be made to work equally well with light emitted at wavelengths in the visible or in the infra-red range.

In a CCD reader, for example, employing an optical bandpass filter before the detector can reduce the ambient light reaching the detector. The combination of the filter and the high power output from the lasers (resulting in very good target illumination) can significantly in-

crease the working range of such detectors, which is especially important for imaging types of detectors.

Although the present invention has been described in at least some embodiments with respect to reading one or two dimensional bar codes and other indicia, it is not limited to such embodiments, but may also be applicable to more complex indicia scanning applications. It is conceivable that the present invention may also find application for use with various machine vision or optical character recognition applications in which information is derived from other types of indicia such as characters or from the surface characteristics of the article being scanned. It may also find application in pen-scanners, mice, telephone scanners, PC-cards and so on.

In all of the various embodiments, the elements of the scan engine may be assembled into a very compact package that allows the entire scanner to be fabricated as a micro-module. Such a module can interchangeably be used as the laser scanning element for a variety of different types of data acquisition systems. For example, the module may be alternately used in a hand-held scanner, a table top scanner attached to a flexible arm or mounting extending over the surface of the table or attached to the underside of the table top, or mounted as a subcomponent or subassembly of a more sophisticated data acquisition system. Control or data lines associated with such components may be connected to an electrical connector mounted on the edge or external surface of the module to enable the module to be electrically connected to a mating connector associated with other elements of data acquisition system.

An individual module may have specific scanning or decoding characteristics associated with it, e.g. operability at a certain working distance, or operability with a specific symbology or printing density. The characteristics may also be defined through the manual setting of control switches associated with the module. The user may also adapt the data acquisition system to scan different types of articles or the system may be adapted for different applications by interchanging modules on the data acquisition system through the use of the simple electrical connector.

The scanning module described above may also be implemented within a self-contained data acquisition system including one or more such components as keyboard, display, printer, data storage, application software, and data bases. Such a system may also include a communications interface to permit the data acquisition system to communicate with other components of a local area network or with the telephone exchange network, either through a modem or an ISDN interface, or by lower power radio broadcast from the portable terminal to a stationary receiver.

It will be understood that each of the features described above, or two or more together, may find a useful application in other types of scanners and bar code readers differing from the types described above. It is specifically contemplated by the applicants that any one or more of the features described or referred to above may form part of the present invention. It is further contemplated that any two or more compatible features, taken together, may also form part of the present invention. Accordingly, it should be understood that, where applicable, features referred to and described in connection with one figure may be used in association with features described in connection with another figure. For example (but without limitation) the micro-optics arrays shown in Figures 5 to 8 could be used either with any of the embodiments of Figures 1 to 3 or alternatively in conjunction with any of the embodiments of Figures 9 to 17. Likewise, it will be understood that the mirror mounting arrangement shown in Figures 15 could be used with any of the embodiments described, including Figures 1 to 4, and not only those embodiments such as Figure 9 which specifically show the mirror being mounted in that particular way.

Claims

1. An optical scanner characterised by:

   (a) at least one vertical cavity surface emitting laser (156) for producing a light beam;
   (b) a first scanner (162) for producing from the light beam an intermediate beam scannable in one direction; and
   (c) a second scanner (160) for receiving the intermediate beam and for producing an output beam scannable two directions.

2. An optical scanner according to claim 1 including an optical element (158) disposed in the light beam between the laser (156) and the first scanner (162).

3. An optical scanner according to claim 2 wherein the optical element (158) is a diffractive optical element.

4. An optical scanner according to claim 2 wherein the optical element (158) is a holographic optical element.

5. An optical scanner according to any one of the preceding claims wherein the first scanner (162) includes a first support and a mirror mounted for scanning motion on the first support.

6. An optical scanner according to any one of the preceding claims wherein the second scanner includes a second support and a second mirror mounted for scanning motion on the second support.

7. A scanner according to any one of claims 1 to 4 wherein the first scanner includes an array of vertical cavity surface emitting lasers (166), individual lasers in the array being sequentially actuated to

provide a composite said intermediate beam scannable in one direction.

8. An optical scanner according to claim 7 including an array of optical elements (164) disposed in front of the array of lasers (166).

9. An optical scanner according to claim 8 wherein the array of optical elements (164) comprises a diffractive optical element array.

10. An optical scanner according to claim 8 wherein the array of optical elements (164) comprises a holographic optical element array.

11. An optical scanner according to any one of claims 1 to 4 wherein the second scanner comprises an array of micromirrors (170), the micromirrors being arranged to scan in a direction different from the said one direction, each said micromirror being driven synchronously with receipt of the intermediate beam, thereby producing an output beam scanning in two directions.

12. An optical scanner according to claim 1 including a common substrate (176) for mounting the first and second scanners (174).

13. An optical scanner according to claim 12 wherein the first and second scanners (172,174) are mounted adjacent to one another on the common substrate (176).

14. An optical scanner according to claim 13 including a folding mirror (182) for reflecting the intermediate beam back from the first scanner (172) to the second scanner (174).

15. An optical scanner according to claim 1 wherein the first scanner includes a laser array and, in front of the array, an optical element array and a switching array, said switching array being sequentially actuated to provide a composite said intermediate beam scannable in one direction.

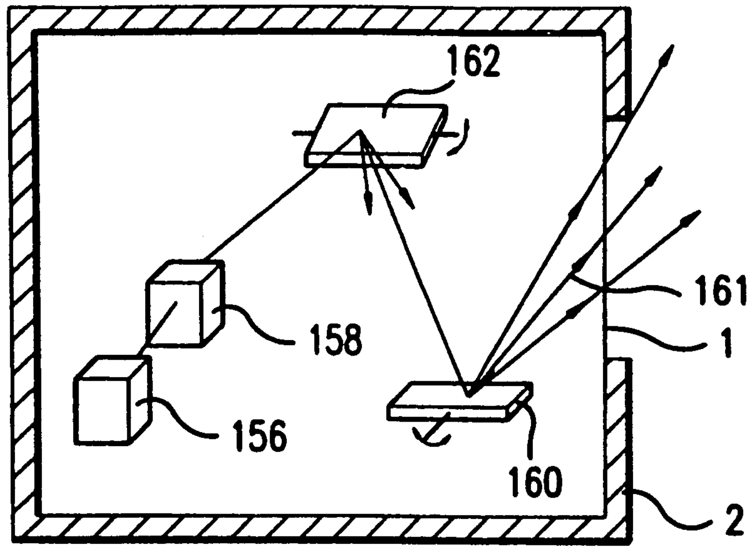


FIG.1

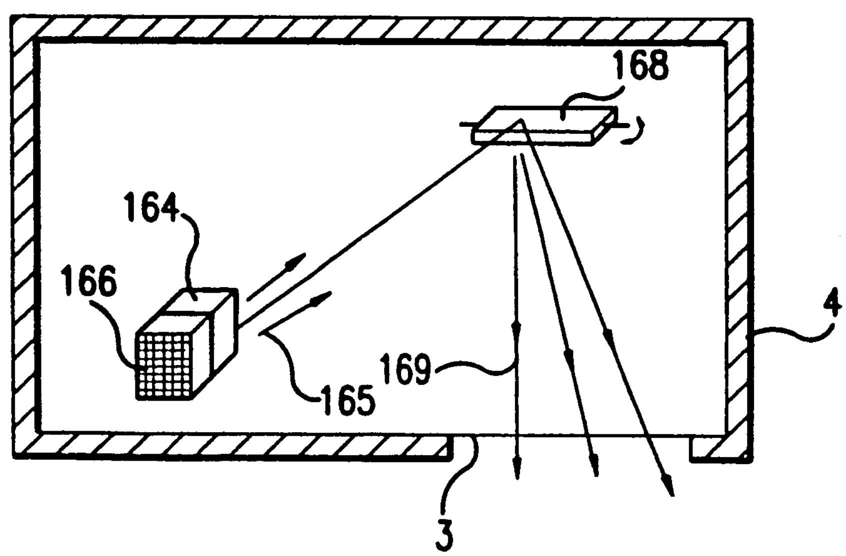


FIG.2

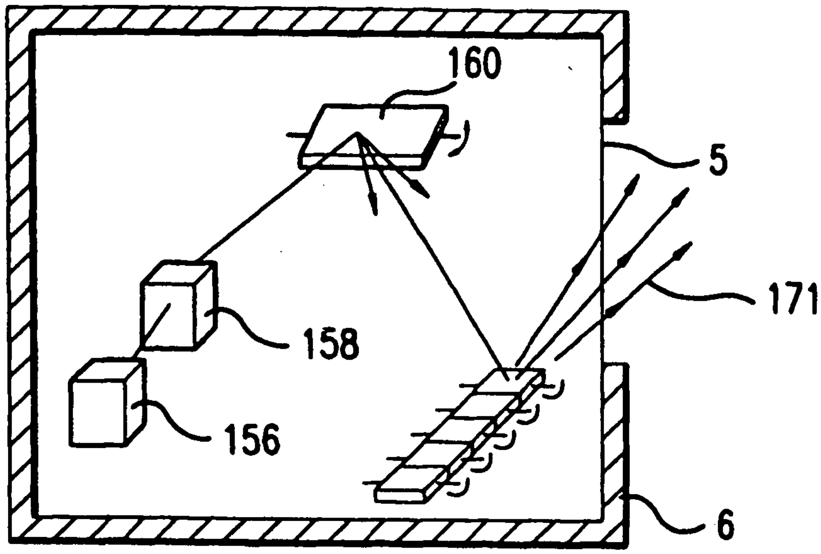


FIG.3

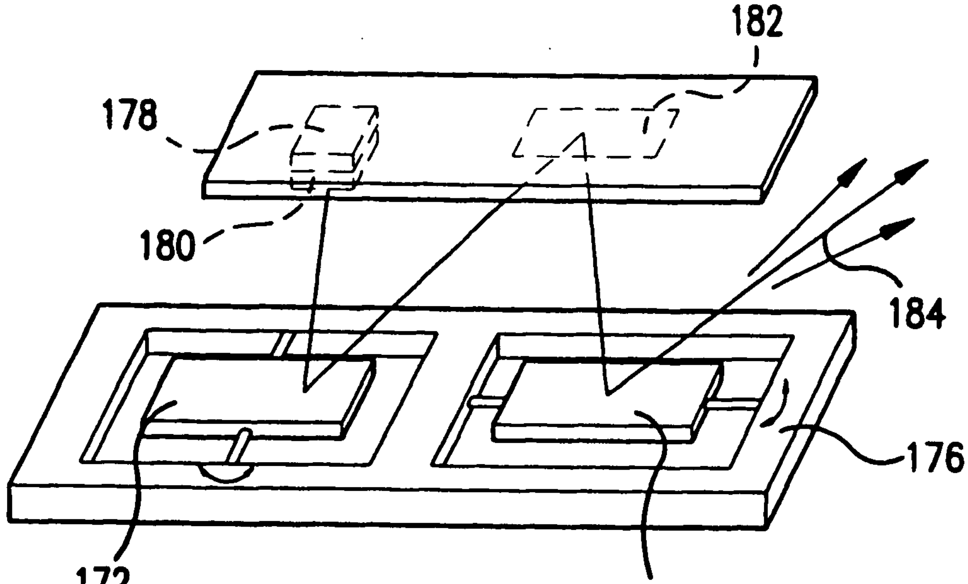


FIG.4A

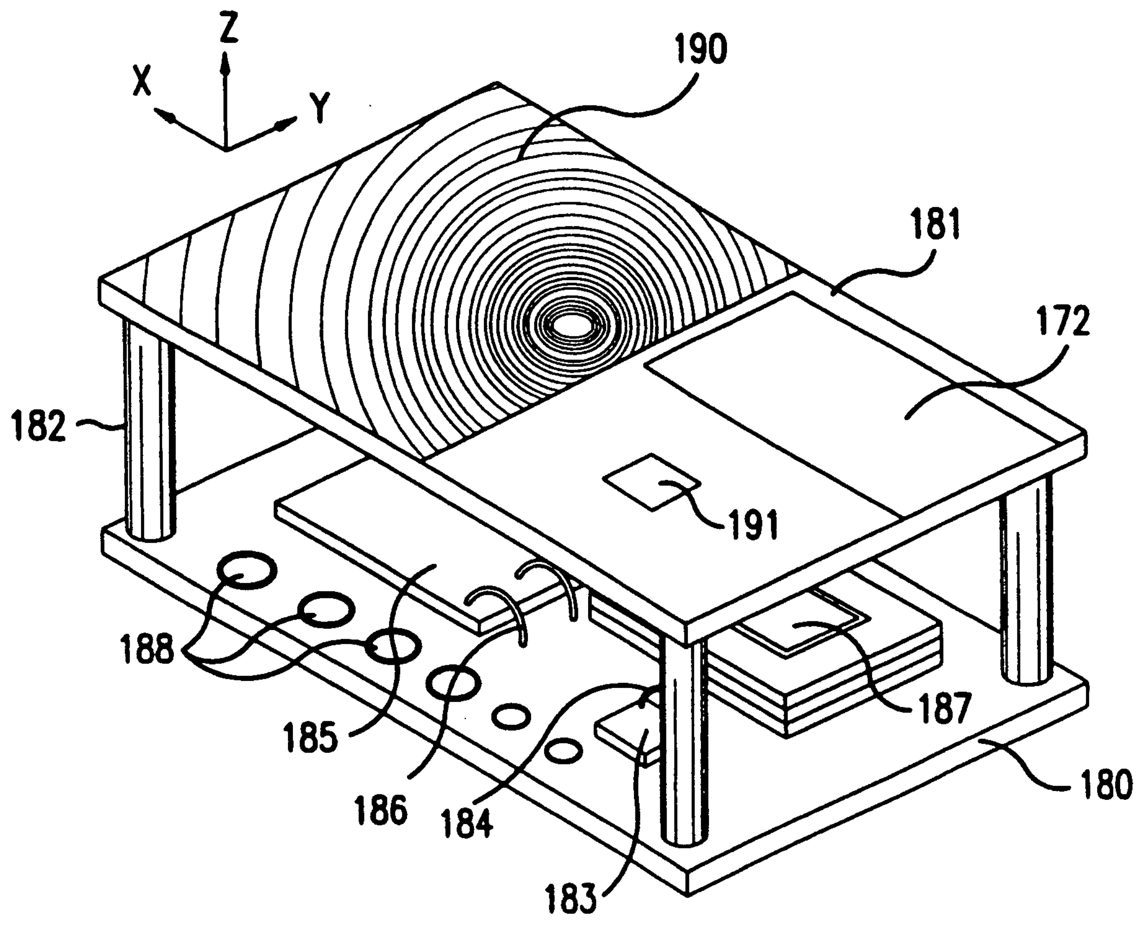


FIG.4B

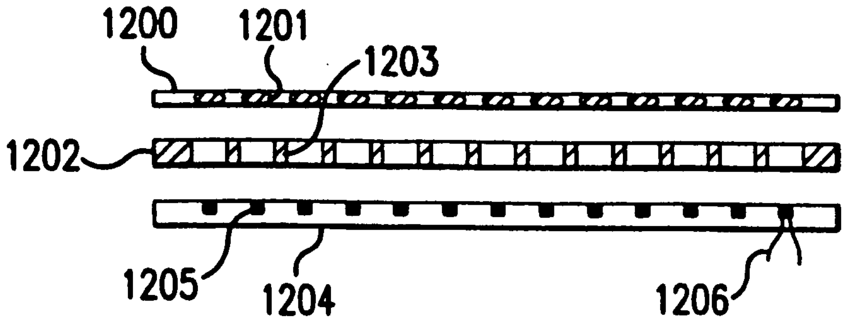


FIG.5

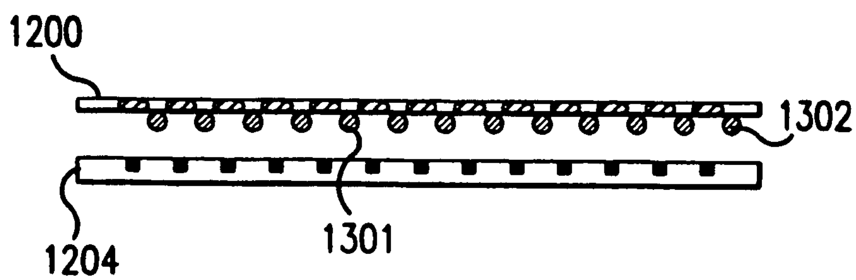


FIG.6

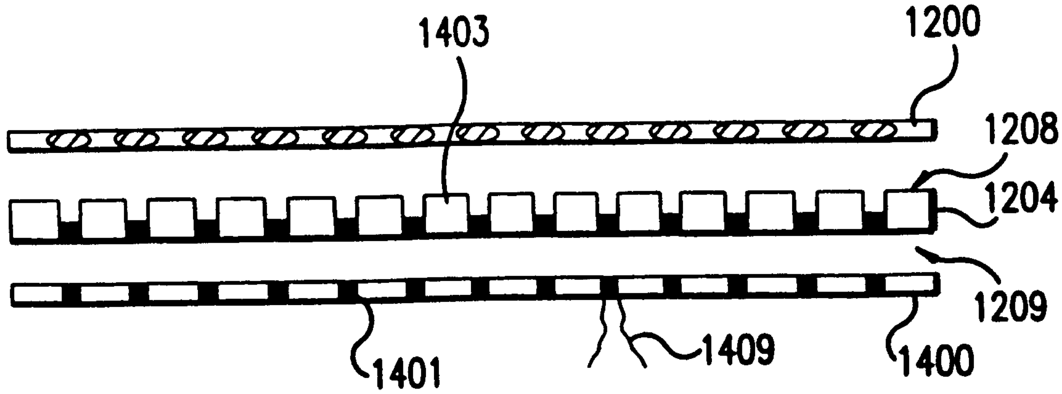


FIG.7

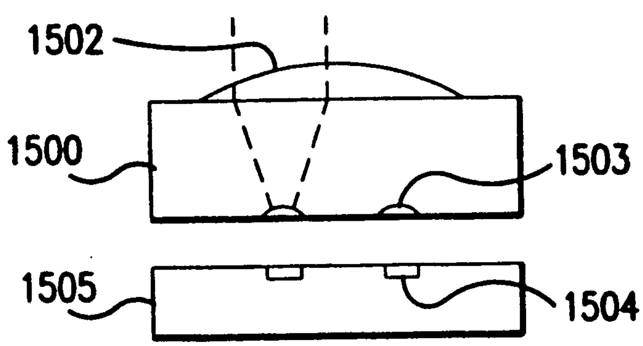


FIG.8A

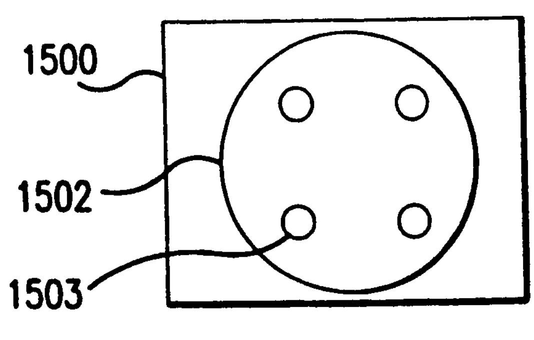
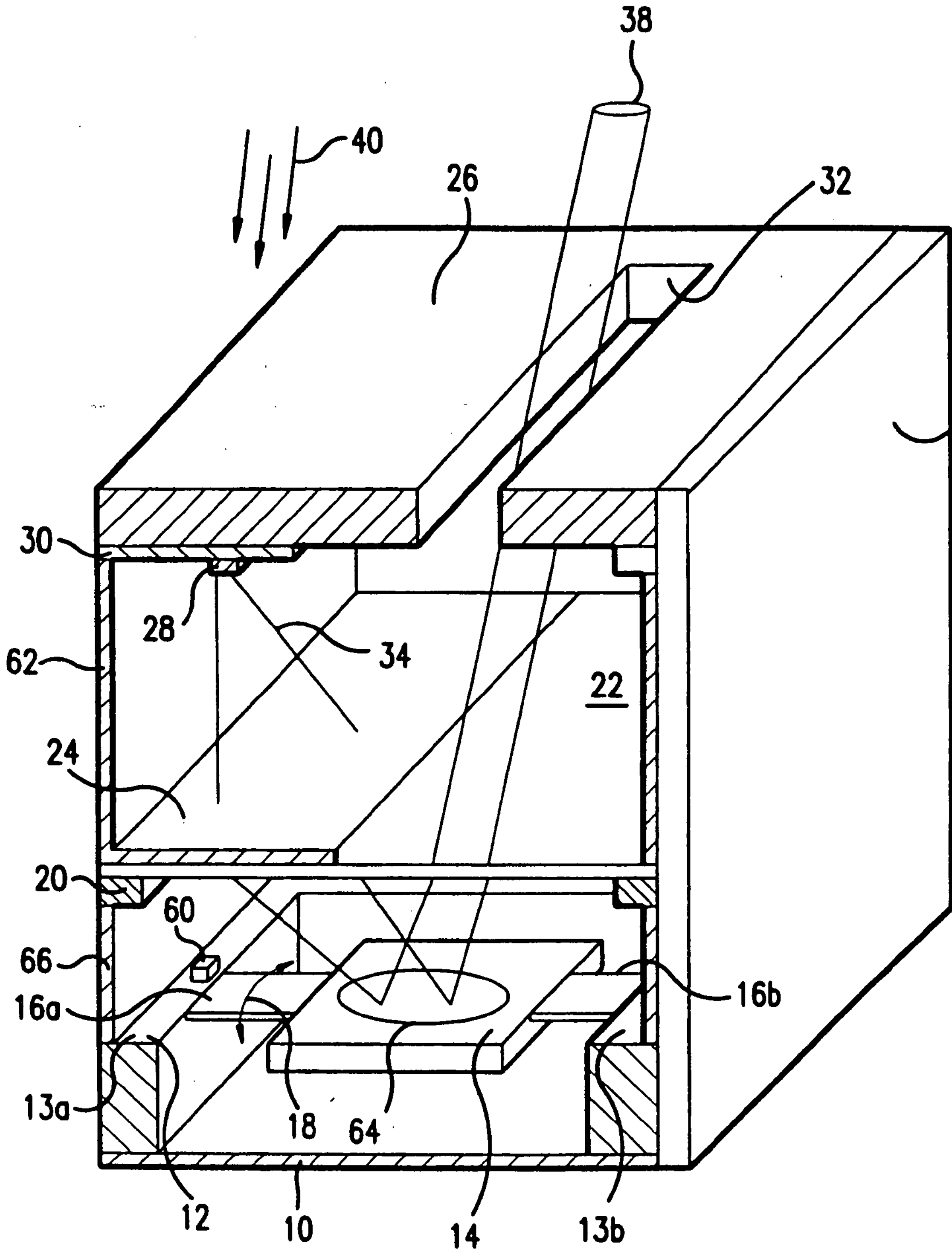


FIG.8B


38
40
26
32
68
30
28
34
62
22
24
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60
66
16a
16b
13a
18
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12
10
14
13b

FIG.9

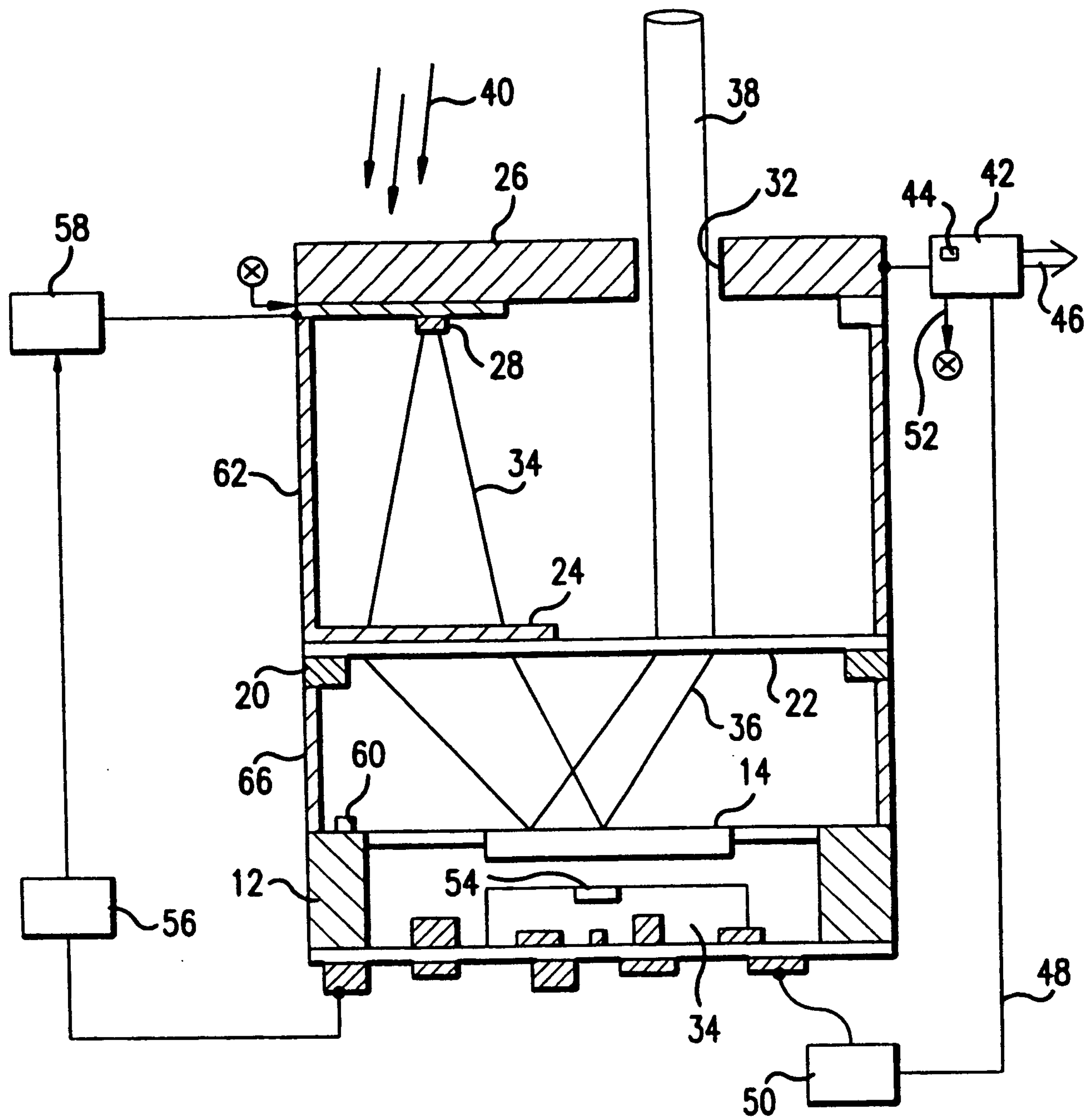
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FIG.10

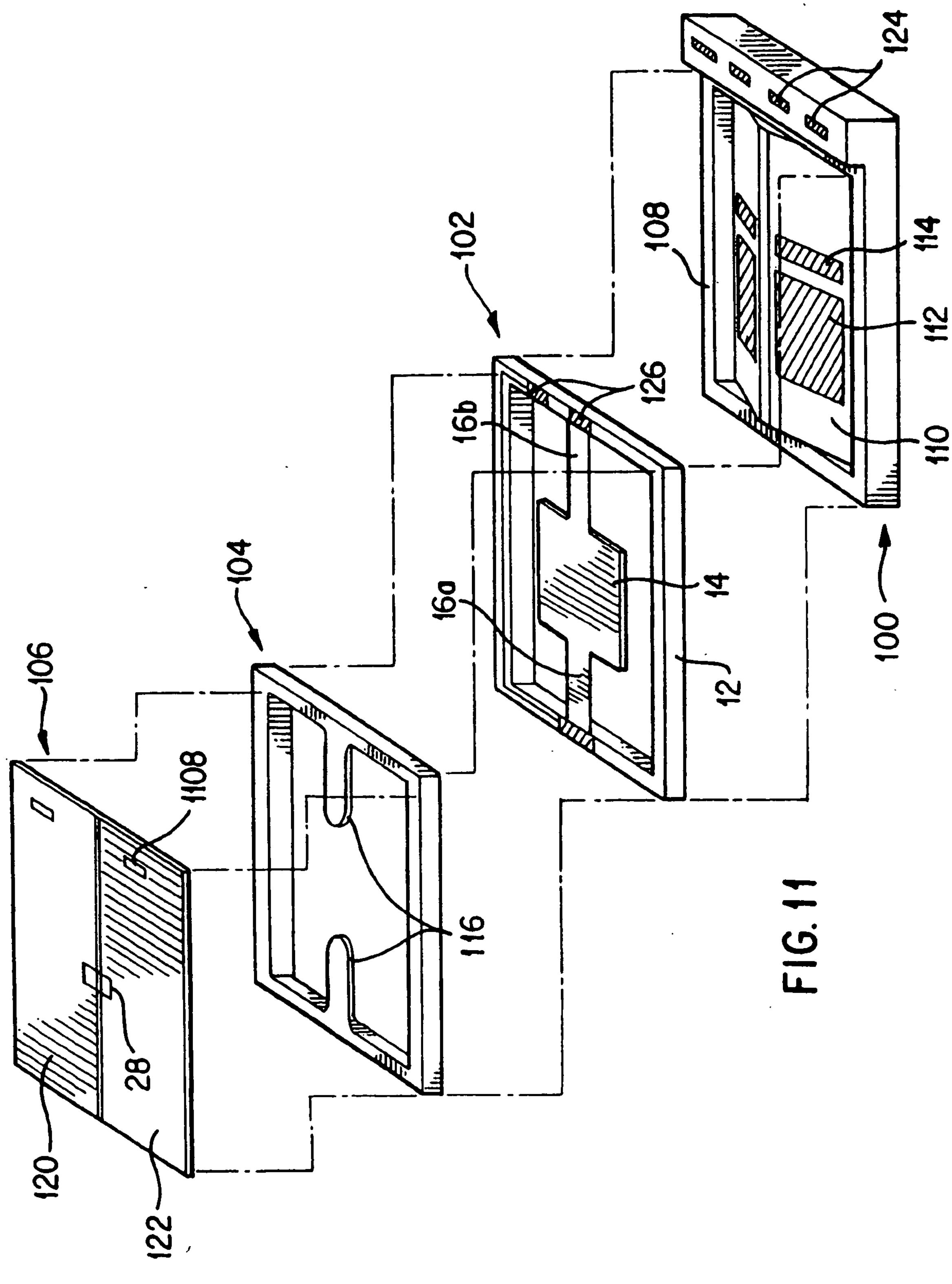
106
1108
120
122
28
104
116
102
16b
126
16a
14
12
108
124
114
112
110
100

FIG. 11

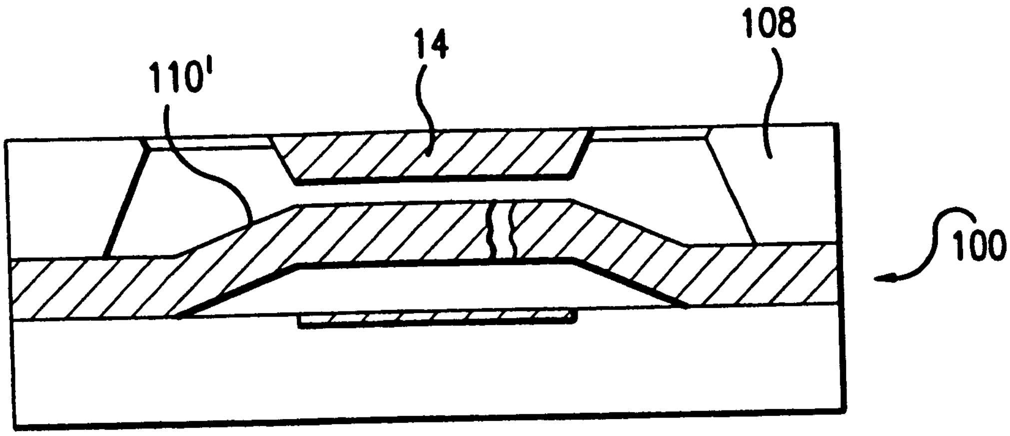

FIG.12A

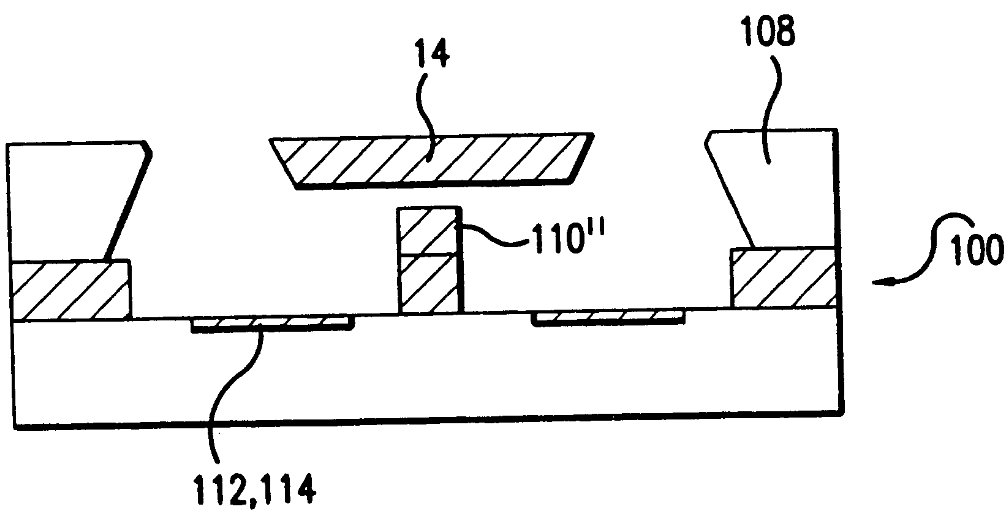

FIG.12B

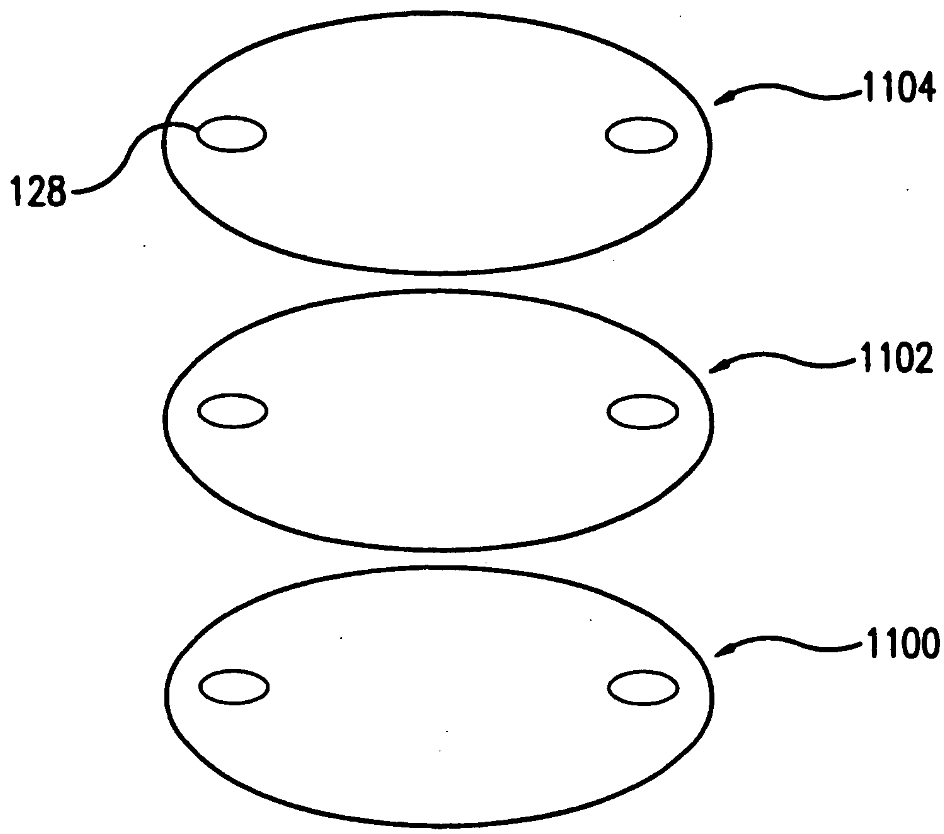

FIG.13

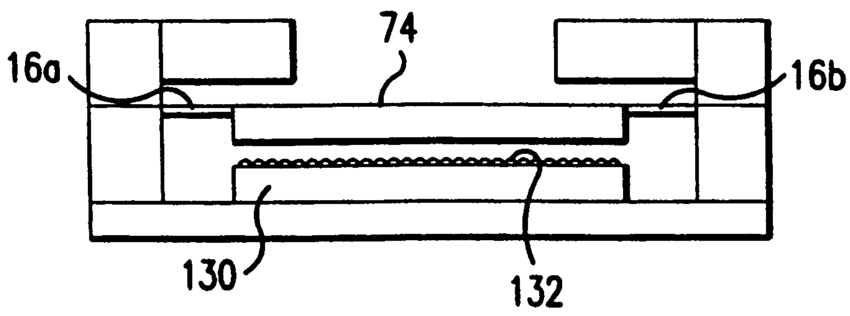

FIG.14

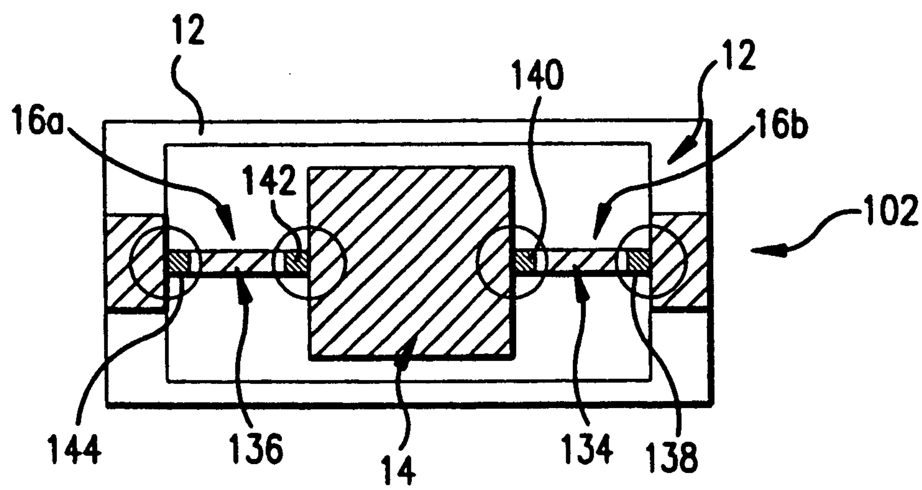

FIG.15

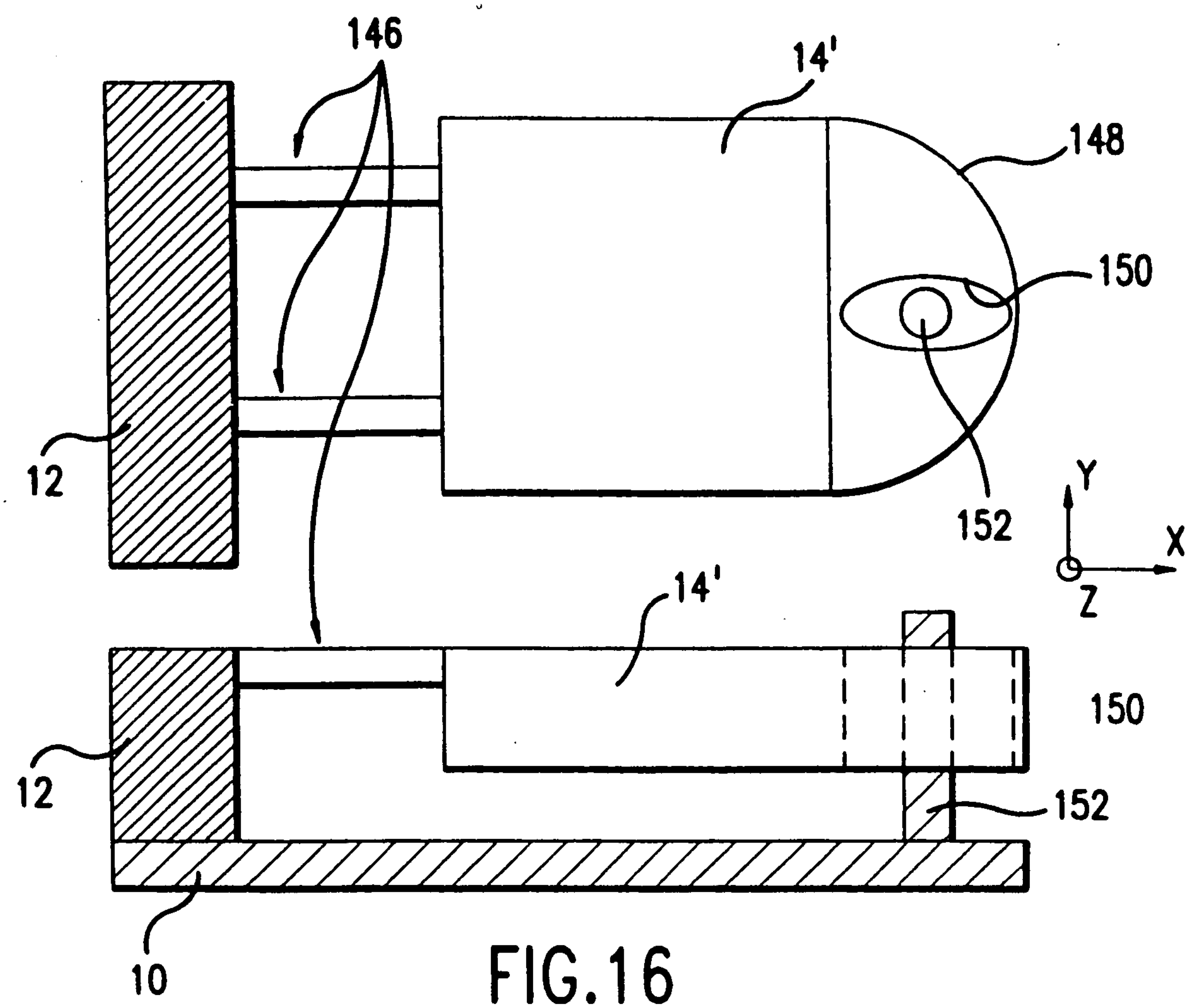

FIG.16

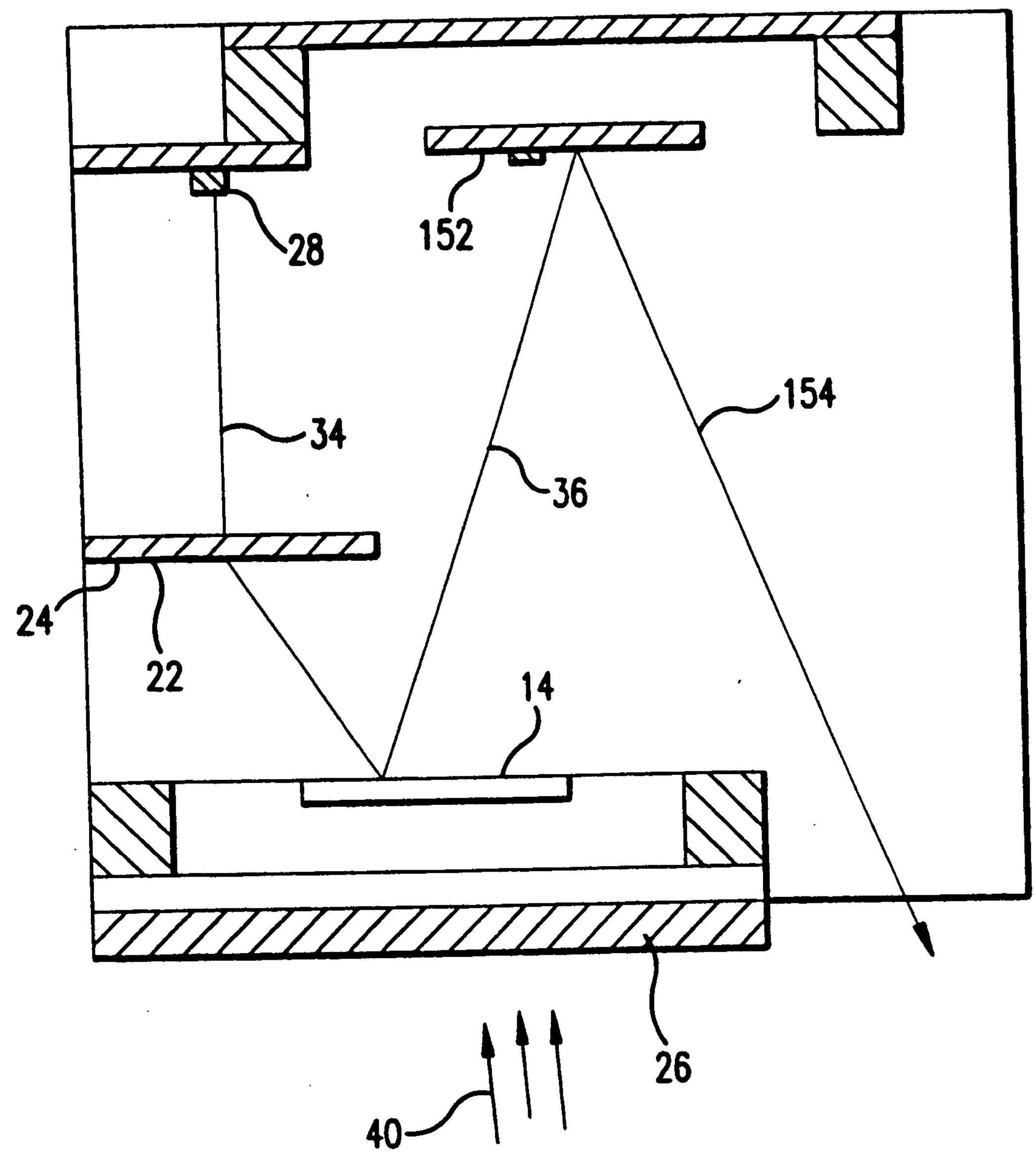

FIG.17

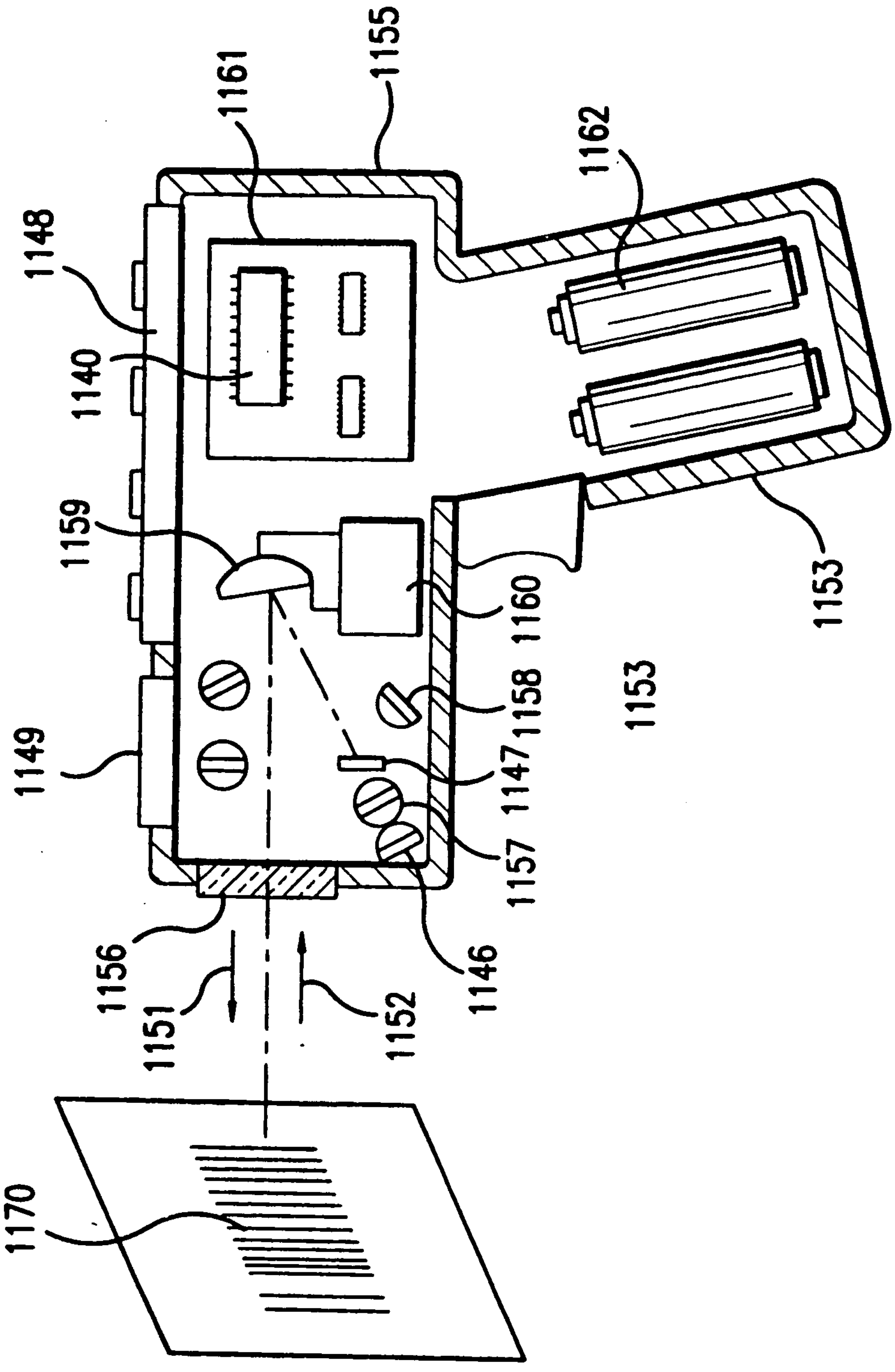
1155
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FIG.18

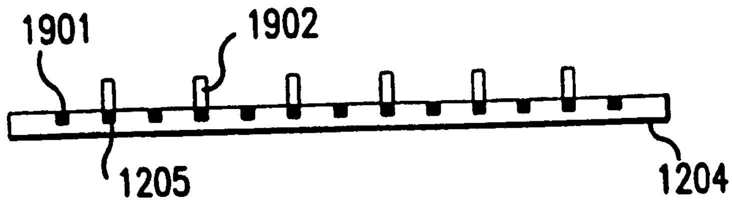

FIG.19A

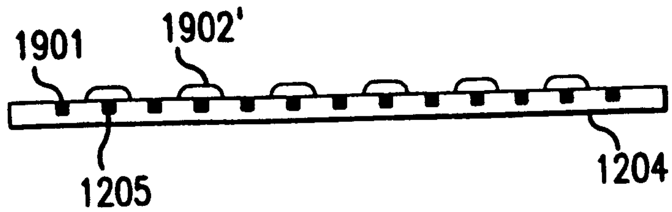

FIG.19B

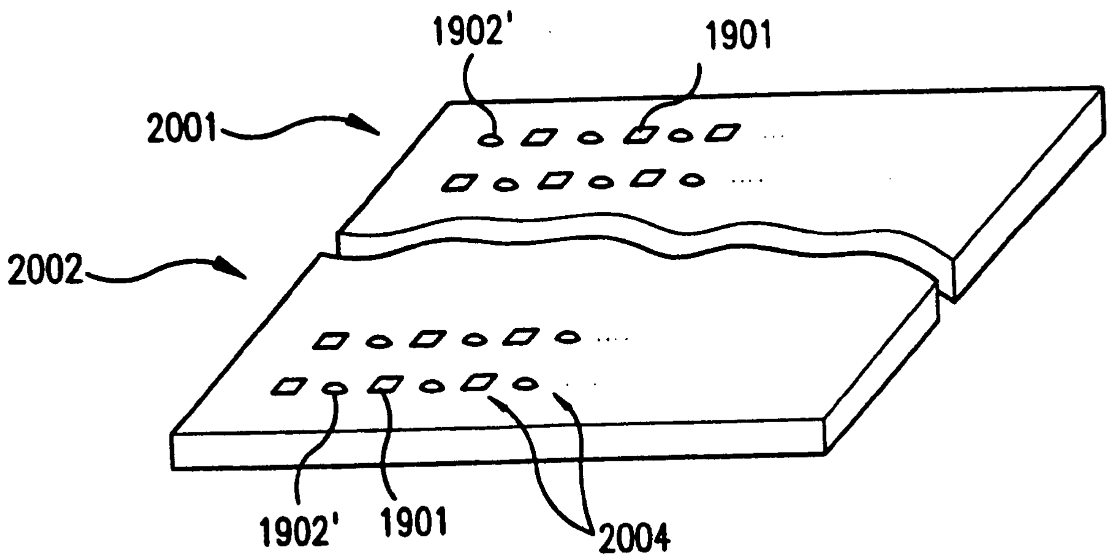

FIG.20

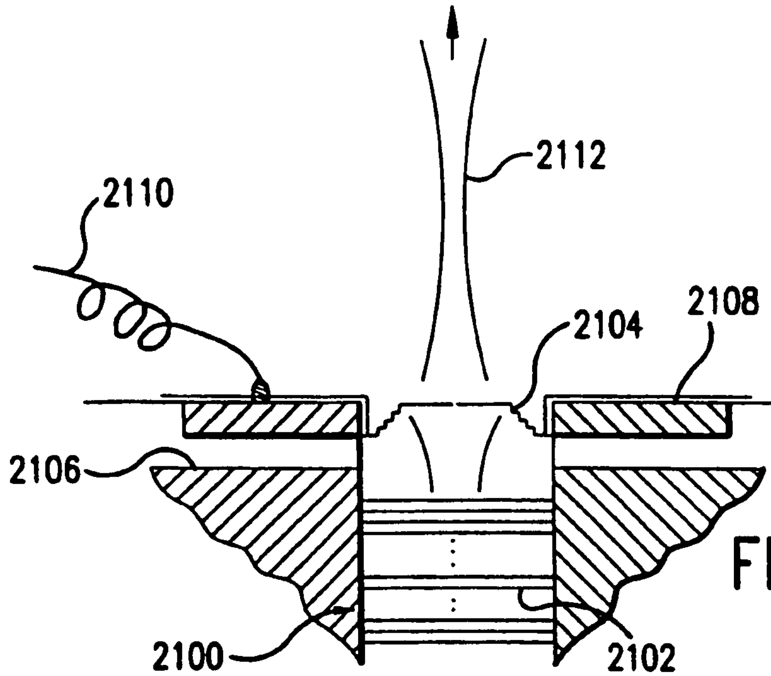

FIG.21

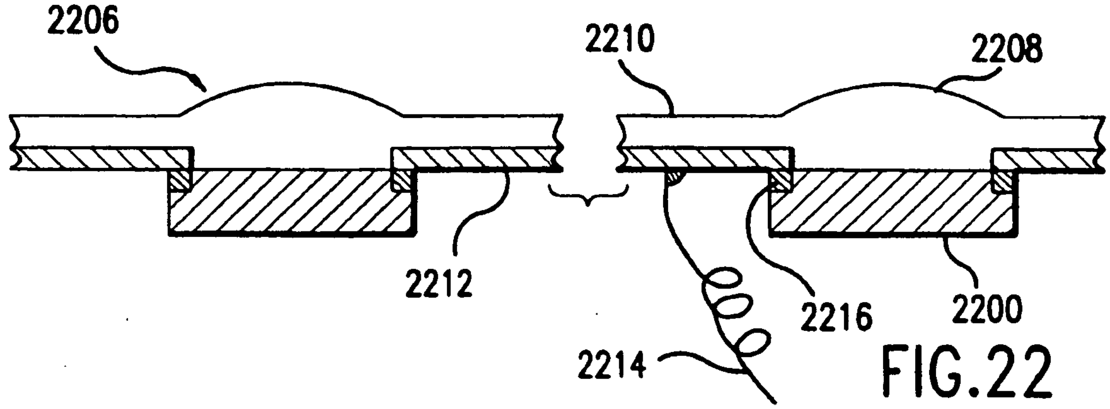

FIG.22

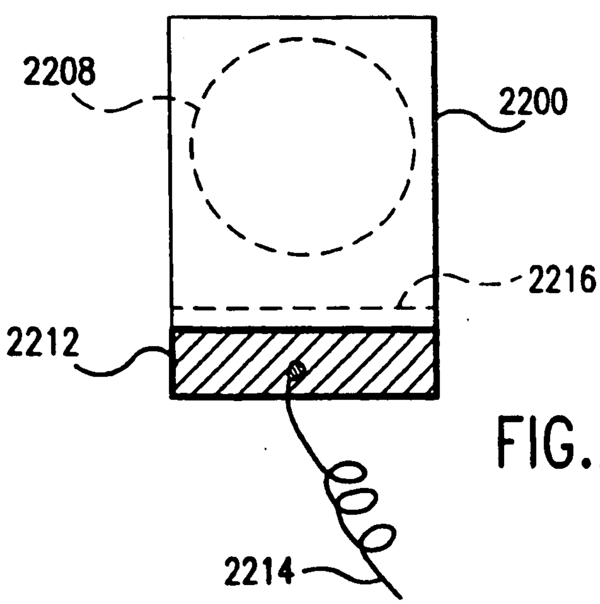

FIG.23

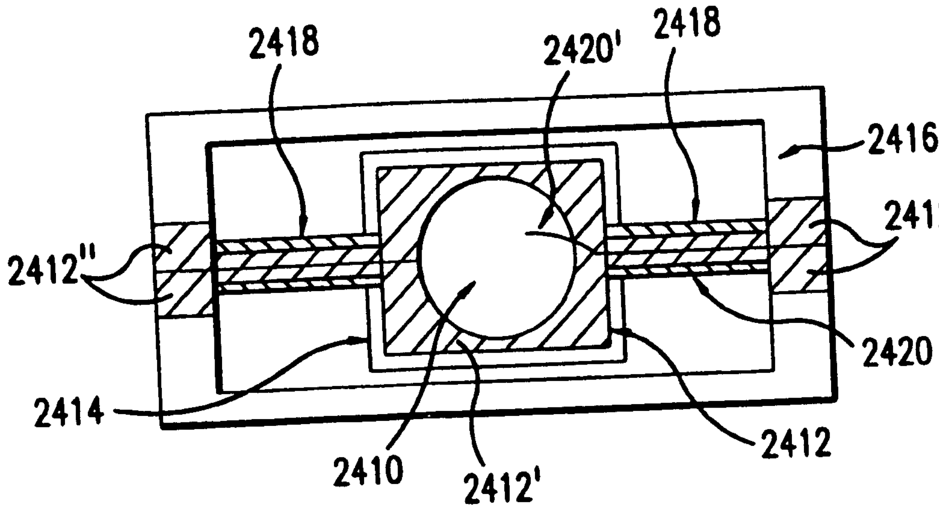
2418
2420'
2418
2416
2412"
2412"
2420
2414
2412
2410
2412'

FIG.24

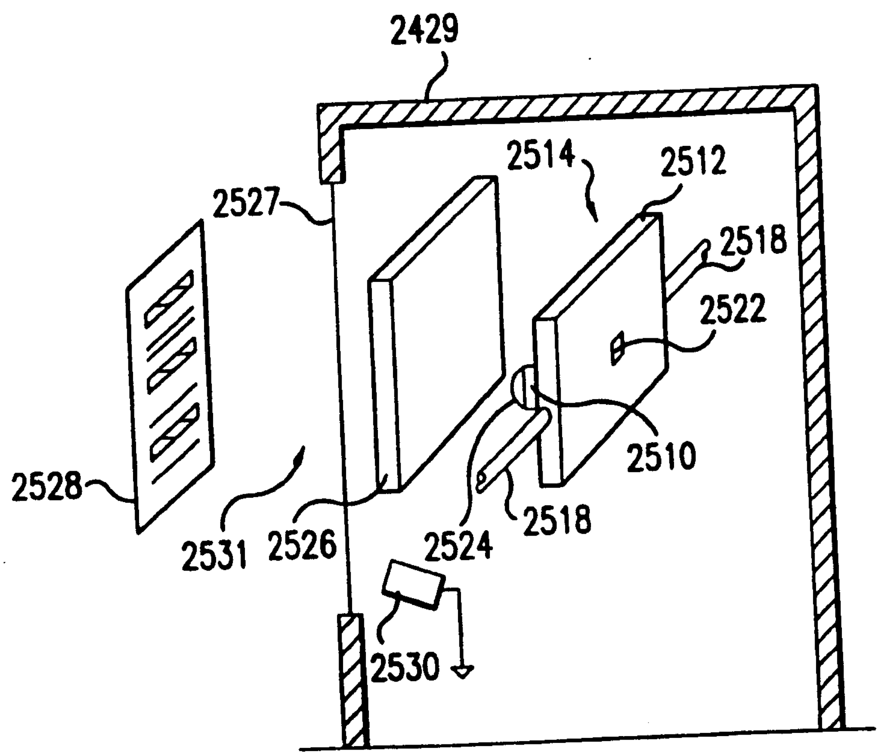
2429
2514
2512
2527
2518
2522
2510
2528
2531
2526
2524
2518
2530

FIG.25

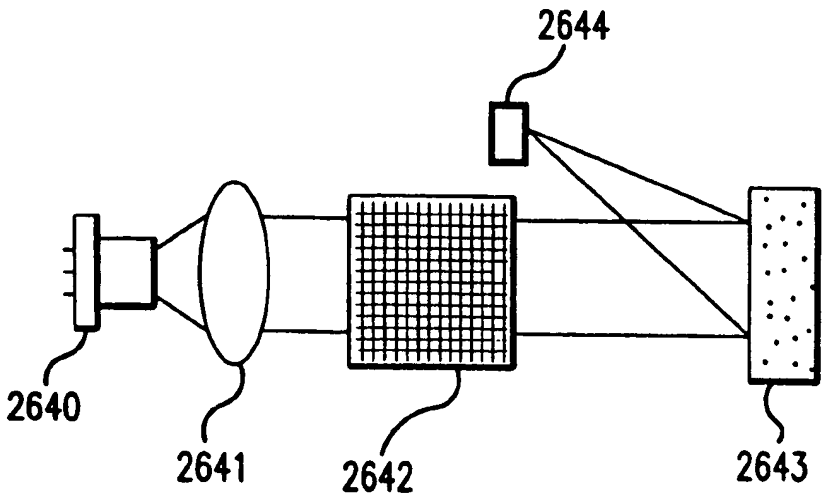

FIG.26a

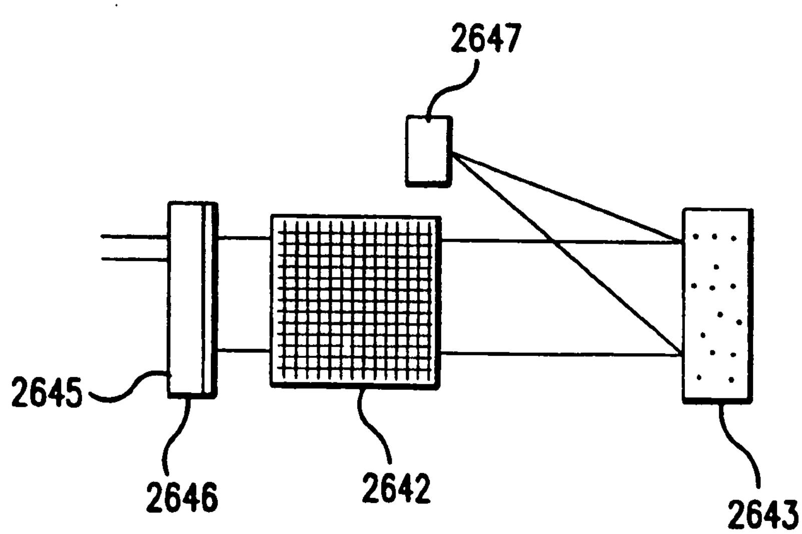

FIG.26b

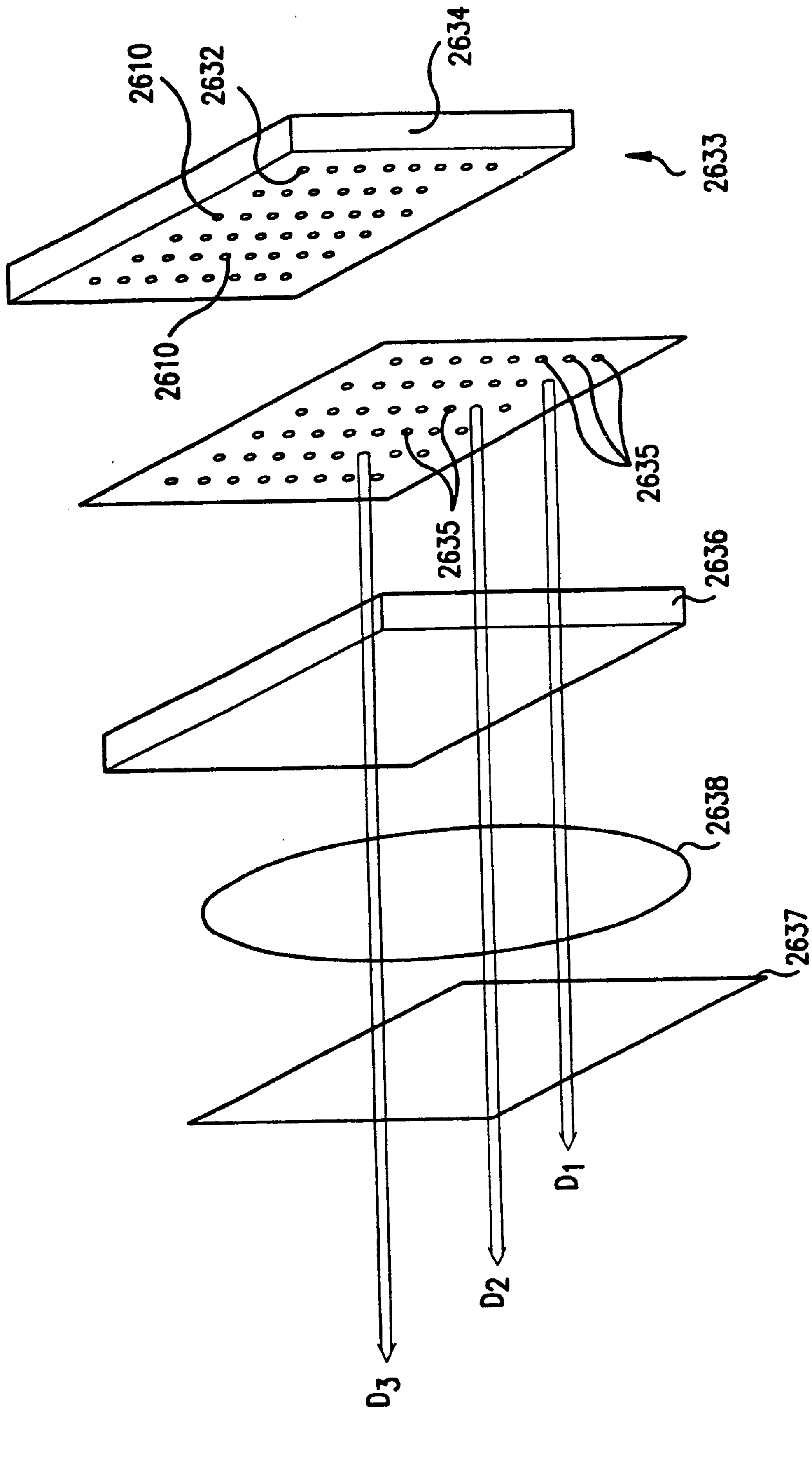

FIG.26c